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Space Assembly Fixtures and Aids

K. A. Bloom and A. N. Lillenas

ROCKWELL INTERNATIONAL CORPORATION
SPACE OPERATIONS AND SATELLITE SYSTEMS DIVISION
DOWNEY, CALIFORNIA 90241

CONTRACT NAS1-15322-TASK 8
JULY 1980

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FOREWORD

The Satellite Systems Division of Rockwell International has been conducting a study to derive concepts and requirements for assembly fixtures and aids necessary to the assembly and maintenance of space platforms, as Task 8.0 of the Erectable Large Space Structures Concept Evaluation and Tradeoff Studies, under Contract NAS1-15322. This work was performed for the Langley Research Center of the National Aeronautics and Space Administration under the direction of Mr. J. A. Allen, the Contracting Officer's Representative, and Mr. J. W. Goslee, the Technical Monitor.

This report documents the findings of Task 8.0, Space Assembly Fixtures and Aids, of the contract study. Included herein is a summation of construction fixture requirements utilizing a literature survey of previous studies as a data base, technology issues relating to future development, construction fixture concepts, a fixture technology and development logic for a fixture system test, and a ROM cost for a development program. Included in the appendix is a design drawing package of the selected concept with sufficient detail to provide costing information for fabrication of a test fixture.

The program was conducted under the direction of Mr. E. Katz, Project Manager for Large Space Structural Systems and Mr. A. N. Lillenas, Project Engineer. Mr. K. A. Bloom was Task Leader, and Mr. J. I. Simonian provided the design analyses.

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1.0 SUMMARY

This study provides a review of the requirements for assembly fixtures and aids that would be applicable in the construction of space platforms in the 1985-2000 time period. It also derived concepts for construction fixtures for satisfying these requirements and the development logic for verification. Factors included platform sizes and types, construction equipment types, systems and payload installations, and Shuttle orbiter capabilities. Study considerations included:

- Small to medium size platforms—deployable and erectable platforms only
- Orbiter-based construction
- Automated construction (RMS-only operations with EVA for contingency, if required)

The results of this study will provide the basis for the development and verification of the technology needed for construction of space operational assembly fixture systems.

A literature search was made of previous studies by industry and government on large space structure design and construction, including the types of construction equipment considered. Using this information as a data base, four model platforms were selected for study: (1) small area erectable, (2) deployable, (3) large area erectable, and (4) linear erectable. A detailed analysis was made of each platform outlining all of the activities performed in the construction process (including construction timelines), the equipment needed to perform each activity, and the fixture/orbiter/platform interfaces. A commonality existed in many cases in the fixture requirements for all four platforms. This analysis provided the basic fixture requirements for the subsequent parametric analysis.

The parametric analysis combines the RMS capability with varying degrees of fixture capability/complexity to determine the size and configuration of the space platform that can be assembled. The purpose of this analysis was to establish a basic assembly fixture that could be used for assembly of a given type/size platform and then, by the addition of other pieces of structure, could be expanded to aid in construction of larger and/or different configurations of platforms. Physical dimensions and characteristics of the fixture obtained by this method were used in the concept design. The resultant fixture concepts shown in this study evolved from the integration of the data from all of the above analyses.

Technology issues relating to the development of an operational fixture include:

1. Method of bringing the space platform construction within RMS operational capability. If construction operations are to be automated (without EVA assist), all points on the platform must be accessible to the RMS.

2. Method of retaining the space platform during construction and/or maintenance.

3. Methods and sequence of installing systems and payloads—includes requirements for special aids and integration of designs.

A technology and development logic was formulated that will result in a construction fixture system development program through integrated ground testing.

2.0 INTRODUCTION

The Large Space Systems Technology (LSST) program was established by the NASA Office of Aeronautics and Space Technology (OAST) to develop the advanced technology of cost-effective, Shuttle-compatible, large area space systems that can be assembled or automatically deployed in orbit to perform missions in the 1985-2000 time frame. Preceding tasks (Tasks 3.0 and 4.0) of this contract (SSD 79-0074) derived technology requirements for a space science and applications platform using a viable platform and service module concept (Figure 2.0-1) with NASA-furnished mission and payload models. Issues pertinent to platform development and on-orbit construction methodology were analyzed, resulting in the identification of technology deficiencies with recommended development timelines. The analysis also provided data for the development of integrated platform system concepts and payload definition and installation options.

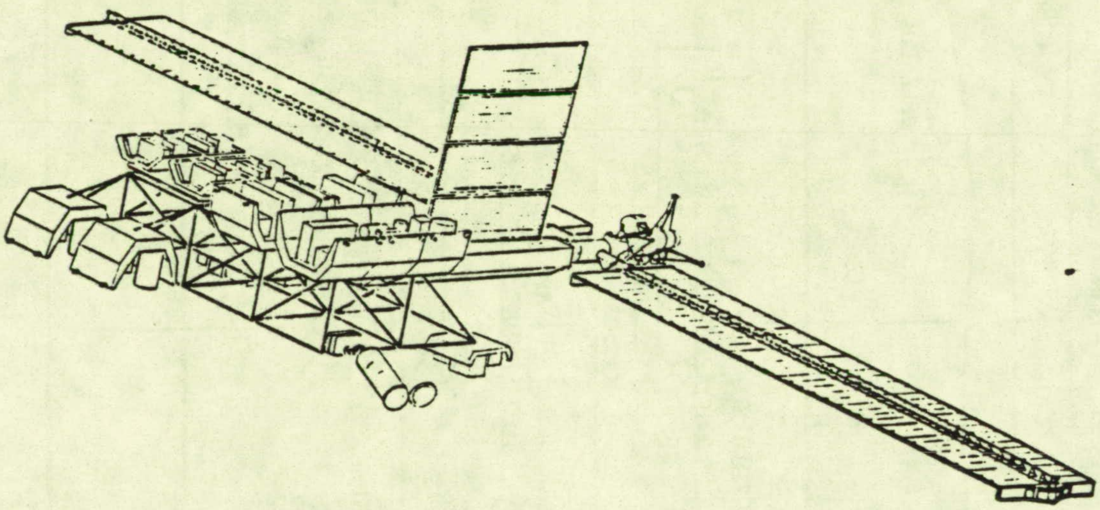


Figure 2.0-1. Science and Applications Platform

Utilizing the data from the Space Science and Applications Platform study certain areas of technologies were defined as requiring system component development and verification on which to base the operational system design. Task 5.0 (also of this contract) developed a PERT-type technique for estimating the scheduling and development requirements for these components, including the construction fixture and aids needed for on-orbit assembly. These requirements encompassed the activities/tasks relevant only to the construction of the platform. That is, individual satellite subsystem designs need be completed only when their characteristics impacted the design of the platform structure and the construction equipment. Figure 2.0-2 depicts a portion of the development planning schedule, in chart form, that incorporates the data used in developing the PERT program (i.e., the interrelationship between each system and the tasks within each system, including task durations).

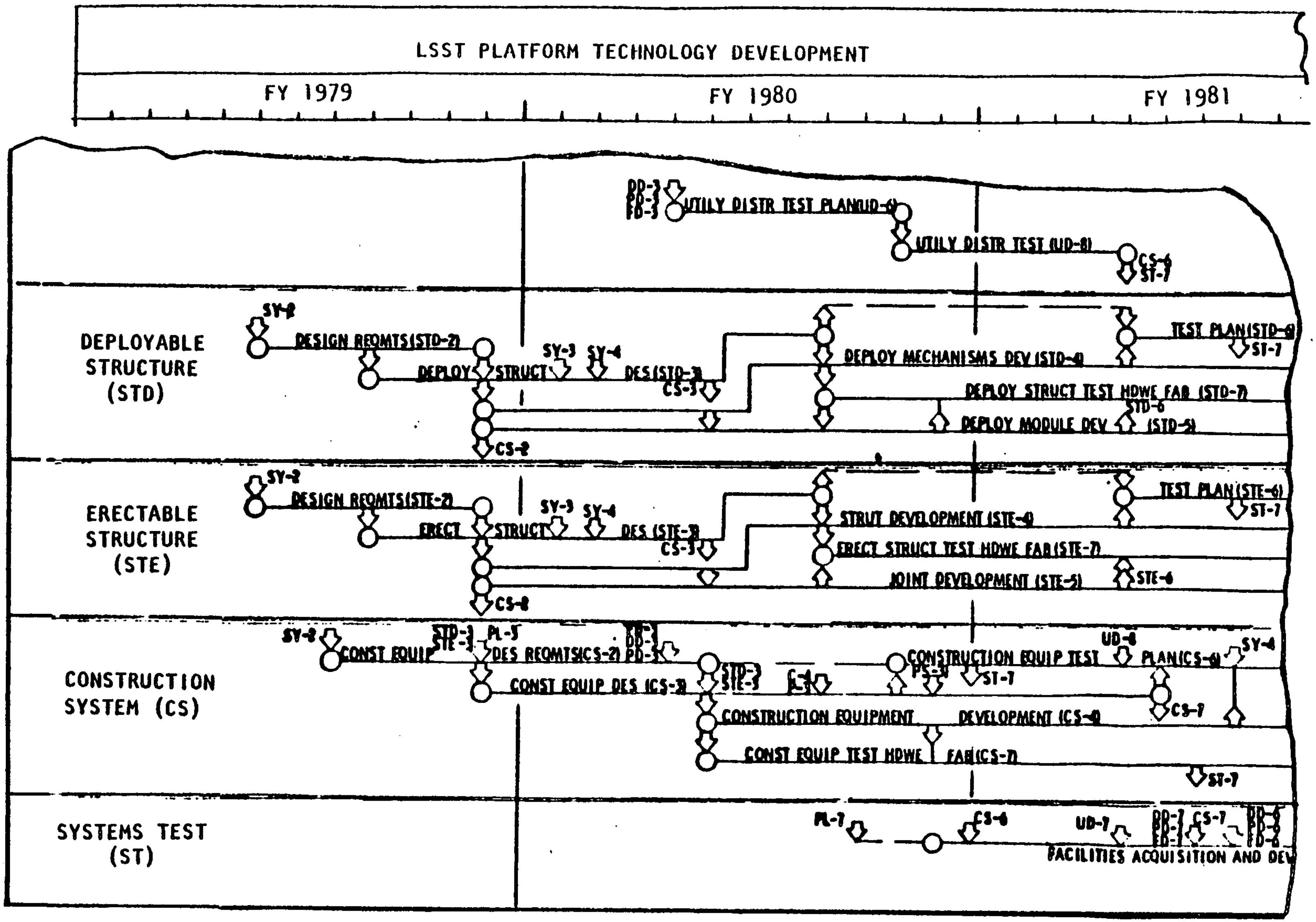


Figure 2.0-2. Science and Applications Platform Technology Development Planning

The results of the above studies determined the necessity for technology development in the principal areas of (1) the design/development of assembly fixtures and aids required for construction of the space platform, and (2) the installation of utility distribution systems on the platform. This study is concerned with the design/development of assembly fixtures and aids utilizing the Shuttle orbiter payload bay as the construction base. As such, it establishes the physical requirements for a construction fixture to the extent that a design concept was formulated in sufficient detail to provide a rough order of magnitude (ROM) cost for fabrication of a test fixture. The study also defines a fixture technology and development logic which would culminate in an integrated construction fixture system ground test, followed by an integrated platform system ground testing program.

3.0 CONSTRUCTION FIXTURE REQUIREMENTS

3.1 CONSTRUCTION EQUIPMENT SURVEY

The initial effort of the current study consisted of a review of existing government and industry study reports in the area of proposed large space structure concepts. Particular emphasis was placed on the search for construction fixture design types recommended for various space platform candidates. From the set of the best document platform construction fixtures for the mid- to small-size platforms, a set of requirements for the construction fixtures was summarized. These requirements then provided a check list of further design analyses, leading to the recommendation of an early development construction fixture concept that would be useful in providing solutions to technology development requirements in the LSS area.

3.1.1 Construction Equipment Document Survey

The data presented here is a compilation of information obtained from a literature search of studies performed by government and industry. A summary of the documents reviewed is shown in Table 3.1-1. Its purpose is to summarize the construction equipment requirements previously defined and to use this information as a data base for further construction requirements definition. To this extent, for each document reviewed, pertinent characteristics relating to the construction equipment and its relationship to the orbiter were defined. These included the specific interfaces (e.g., structural attachments) with the orbiter, location in the payload bay, axis of construction, and the specific functions which were performed during the construction operations. From the studies listed in the table, only the five shown in Figure 3.1-1 were shown

Table 3.1-1. Summary of Literature Search Documents

- Automatic In-Orbit Assembly of Large Space Structures; Lockheed Missiles and Space Co. (Paper, April 1979)
- Deployable Orbital Service Platform Conceptual Systems Study; McDonnell Douglas (March 1979)
- Systems Definition Study for Shuttle Demonstration Flights of Large Space Structures; Grumman Aerospace Corp. (April 1978)
- Erectable Space Platform for Space Sciences and Applications; Rockwell International Corporation (March 1979)
- Large Space System Automated Assembly Technique; General Dynamics/General Electric (Paper, May 1979)
- Space Construction Systems Analysis Study; Rockwell International Corporation (June 1979)
- Orbital Construction Demonstration Article Study; Grumman Aerospace Corp. (December 1976)
- Large Space Erectable Structures—Building Block Structures Study; Boeing Aerospace Company (April 1977)

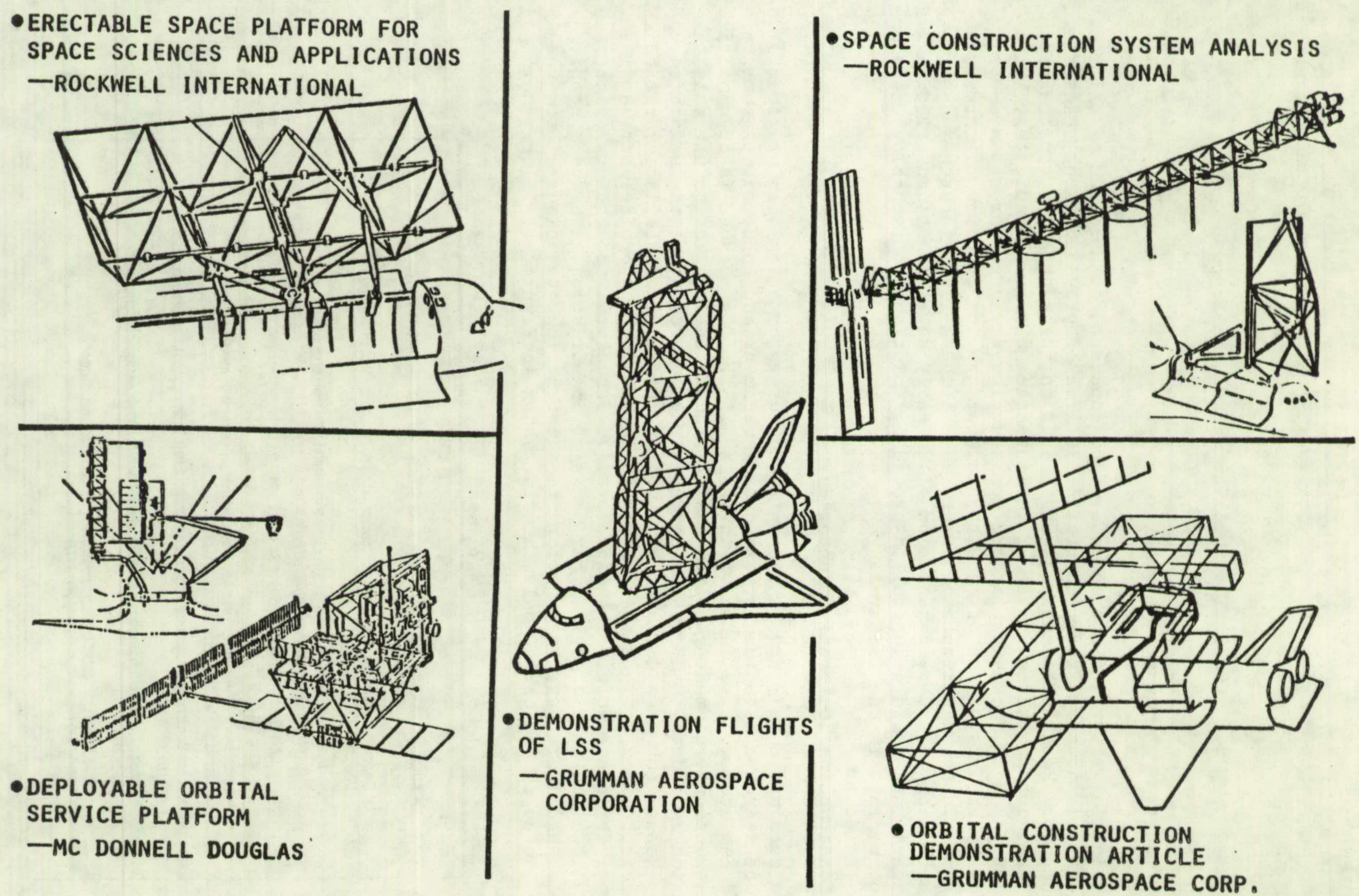


Figure 3.1-1. Literature Search Studies Selected

in detail. The remaining studies were omitted from detail analysis due to lack of sufficient construction definition. The literature search detailed analysis is presented in Appendix A.

Excluded from this documentation review was the construction of large space systems using in-space fabrication (beam machines), with the exception of a hybrid study performed by Grumman Aerospace. The Grumman study defined construction of an erectable space platform using in-space fabricated tri-beams. This method employed the use of construction equipment as well as the beam machine.

3.1.2 Equipment Requirements Summary

Upon completion of the detailed definition of the construction equipment requirements, summaries were prepared delineating the actual equipment requirements (Table 3.1-2) and the assembly operations for which they were used (Table 3.1-3).

Table 3.1-2. Construction Equipment Requirements Summary

STUDIES	ASSEMBLY OPERATIONS AND EQUIPMENT USED					
	PLATFORM STRUCTURE ASSEMBLY	UTILITY DISTRIBUTION SYSTEMS INSTALLATION	SYSTEMS/ PAYLOAD INSTALLATION	CHECKOUT & ALIGNMENT	DOCKING/ BERTHING	ORBITER PACKAGING
PLATFORM CONSTRUCTED IN ONE ORBITER FLIGHT						
<u>DEPLOYABLE</u> McDONNELL DOUGLAS	1) ORBITER BERTHING ASSY (OBA) 2) RMS WITH SPEC. END EFFECTOR	NONE—SYSTEMS INTEGRAL WITH STRUCTURE	1) RMS WITH SPEC. END EFFECTOR 2) OBA (RETENTION)	1) ELECTRICAL CHECKOUT—OBA/ORBITER 2) ALIGNMENT—NONE STATED	1) RMS 2) OBA (VISUAL AIDS NOT STATED)	NO SPECIAL CONSIDER-ATIONS
<u>ERECTABLE</u> ROCKWELL INTERNATIONAL	1) PLATFORM ASSEMBLY FIXTURE (PAF)	1) RMS WITH SPEC. END EFFECTOR 2) PAF	1) RMS WITH SPEC. END EFFECTOR 2) PAF (RETENTION)	1) ELEC. C/O—PAF/ORBITER 2) ALIGNMENT—NONE STATED	1) RMS	FOLDING/ COLLAPSING DESIGN REQ'D TO FIT INTO PAYLOAD BAY
<u>HYBRID</u> IN-SPACE FABRICATION/ ERECTABLE GRUMMAN AEROSPACE CO.	1) AUTOMATIC BEAM BUILDER (ABB) WITH TRIPOD CANISTER 2) PAF 3) RMS WITH SPEC. END EFFECTOR(S) 4) CABLE TENSIONING DEVICE 5) TOOL FOR JOINING BEAMS	1) RMS WITH SPECIAL END EFFECTORS 2) PLATFORM ASSEMBLY FIXTURE (PAF)	1) RMS WITH SPECIAL END EFFECTORS 2) PAF (RETENTION)	1) ELECTRICAL CHECKOUT—PAF/ORBITER 2) ALIGNMENT—NONE STATED	1) PAF (OPTIONAL) 2) RMS	1) REMOVABLE HORIZONTAL ARMS 2) TELESCOPING MOUNT
PLATFORM CONSTRUCTED IN MORE THAN ONE ORBITER FLIGHT						
<u>HYBRID</u> DEPLOYABLE/ ERECTABLE GRUMMAN AEROSPACE CO.	1) SUBASSEMBLY FIXTURE 2) RMS W/SPEC. END EFF. 3) CABLE/TEN-SION ROD TENSIONING DEVICE 4) JOINT ATTACHMENT. TOOL 5) RMS ON PLA PLATFORM W/SPEC. END EFFECTORS	NONE STATED	NONE STATED	1) ALIGNMENT—EVA—PRISMS WITH TELE-SCOPE 2) ELEC. C/O—UNKNOWN PLATFORM RMS THROUGH ORBITER DOCKING INTERFACE	NONE	FOLDED/ DEPLOYED
<u>ERECTABLE</u> ROCKWELL INTERNATIONAL	1) ASSY FIXT. 2) STRUT ASSY FIXTURE 3) RMS W/SPEC. END EFF. 4) CHERRY PICKER (OPTIONAL) 5) MMU (OPTIONAL)	1) RMS WITH SPEC. END EFFECTORS 2) CHERRY PICKER (OPTIONAL) 3) MMU (OPTIONAL)	1) RMS WITH SPEC. END EFFECTORS 2) CHERRY PICKER (OPTIONAL) 3) MMU (OPTIONAL)	NONE STATED	ASSY FIXTURE TO ORBITER DOCKING CAPA-BILITY	FOLDING/ COLLAPSING DESIGN REQ'D IN P/L BAY

Table 3.1-3. Construction Equipment Functions Summary

DEPLOYABLE STRUCTURE (DS)	ERECTABLE STRUCTURE (ES)	HYBRID STRUCTURE (HS)
SIZE—CLASS I: ONE ORBITER FLIGHT FOR ASSEMBLY COMPLETION		
<u>FIXTURE</u> 1) DEPLOY FROM P/L BAY TO CONSTRUCTION LOCATION 2) MATE WITH PLATFORM BERTHING PORT 3) RETAIN PLATFORM DURING DEPLOYMENT 4) PROVIDE ELECTRICAL INTERFACE BETWEEN ORBITER AND PLATFORM (ON-ORBIT CHECKOUT AND DEPLOYMENT) 5) ROTATE/TRANSLATE PLATFORM TO FACILITATE RMS OPERATIONS 6) RELEASE PLATFORM <u>OTHER EQUIPMENT</u> 1) REMOVE PLATFORM FROM PAYLOAD BAY AND INSTALL ON FIXTURE 2) REMOVE PAYLOADS FROM PAYLOAD BAY AND INSTALL ON PLATFORM	<u>FIXTURE</u> 1) RETAIN UNIONS IN PROPER POSITION DURING ASSEMBLY 2) RETAIN PLATFORM DURING ASSEMBLY AND SYSTEMS/PAYLOAD INSTALLATION 3) TRANSLATE PLATFORM IN X,Y AXIS DURING ASSEMBLY 4) PROVIDE ELECTRICAL INTERFACE BETWEEN PLATFORM AND ORBITER 5) PROVIDE COMPATIBILITY WITH PAYLOAD BAY PACKAGING <u>OTHER EQUIPMENT</u> 1) REMOVE/TRANSPORT CONSTRUCTION MATERIALS, SYSTEMS, AND PAYLOADS FROM PAYLOAD BAY TO CONSTRUCTION LOCATION 2) ATTACH JOINTS/STRUTS TO ASSEMBLE PLATFORM 3) INSTALL UTILITY DISTRIBUTION SYSTEMS 4) INSTALL PAYLOADS/SYSTEMS 5) TRANSPORT/ATTACH PLATFORM TO POWER MODULE	<u>FIXTURE</u> 1) RETAIN BEAMS IN PROPER POSITION DURING ASSEMBLY 2) RETAIN COMPLETED BAY(S) IN TRANSLATED POSITION (MOVED VERTICALLY) 3) RETAIN COMPLETE ASSEMBLY DURING SYSTEMS/PAYLOADS INSTALLATION 4) PROVIDE ELECTRICAL INTERFACE BETWEEN PLATFORM AND ORBITER 5) PROVIDE COMPATIBILITY WITH PAYLOAD BAY PACKAGING <u>OTHER EQUIPMENT</u> 1) FABRICATE TRI-BEAMS (AUTOMATIC BEAM BUILDER) 2) INSTALL BEAMS IN FIXTURE AND JOIN 3) INSTALL TENSION CABLES 4) INSTALL UTILITY DIST. SYSTEMS 5) REMOVE SYSTEMS/PAYLOADS FROM PAYLOAD BAY AND INSTALL 6) TRANSLATE COMPLETED BAY TO NEXT POSITION 7) ASSEMBLE AND DISASSEMBLE FIXTURE
SIZE—CLASS II: MORE THAN ONE ORBITER FLIGHT TO COMPLETE ASSEMBLY		
NOT APPLICABLE	<u>FIXTURES</u> 1) RETAIN STRUTS DURING UNFOLDING AND RIGIDIZING 2) RETAIN JOINTS/STRUTS DURING ASSEMBLY AND RELEASE WHEN ASSEMBLED 3) POSITION (TRANSLATE) PLATFORM IN Z-AXIS DURING ASSEMBLY TO MAINTAIN RMS CAPABILITY 4) PROVIDE ELECTRICAL INTERFACE BETWEEN ORBITER AND PLATFORM 5) PROVIDE COMPATIBILITY WITH PAYLOAD BAY PACKAGING <u>OTHER EQUIPMENT</u> 1) TRANSPORT MATERIALS, SYSTEMS, & PAYLOADS FROM P/L BAY TO FIXTURE 2) UNFOLD STRUTS AND RIGIDIZE 3) INSTALL UTILITY DISTRIB. SYSTEMS 4) INSTALL PAYLOADS/SYSTEMS	<u>FIXTURES</u> 1) RETAIN CORNER POSTS IN PROPER POSITION AND ORIENTATION DURING ASSEMBLY 2) RELEASE CUBE ASSEMBLY <u>OTHER EQUIPMENT</u> 1) REMOVE FIXTURE FROM PAYLOAD BAY AND INSTALL ON LONGERON 2) INSTALL POSTS IN FIXTURE 3) REMOVE BEAMS FROM PAYLOAD BAY, DEPLOY AND INSTALL IN FIXTURE 4) JOIN POSTS TO BEAMS 5) INSTALL TENSION RODS 6) TIGHTEN TENSION RODS 7) TRANSPORT CELL ASSEMBLIES TO PLATFORM AND ATTACH 8) ALIGN PLATFORM STRUCTURE

3.2 CONSTRUCTION ACTIVITIES AND EQUIPMENT REQUIREMENTS ANALYSES

Utilizing the information obtained in the construction equipment document survey as a data base, four model platforms (Figure 3.2-1) were selected for an in-depth analysis of fixture requirements. The platforms were categorized into two classes:

- *Class I.* Platforms that would be assembled during one orbiter flight—small area erectable, and deployable.
- *Class II.* Platforms requiring more than one orbiter flight or assembly—large area erectable, and linear erectable.

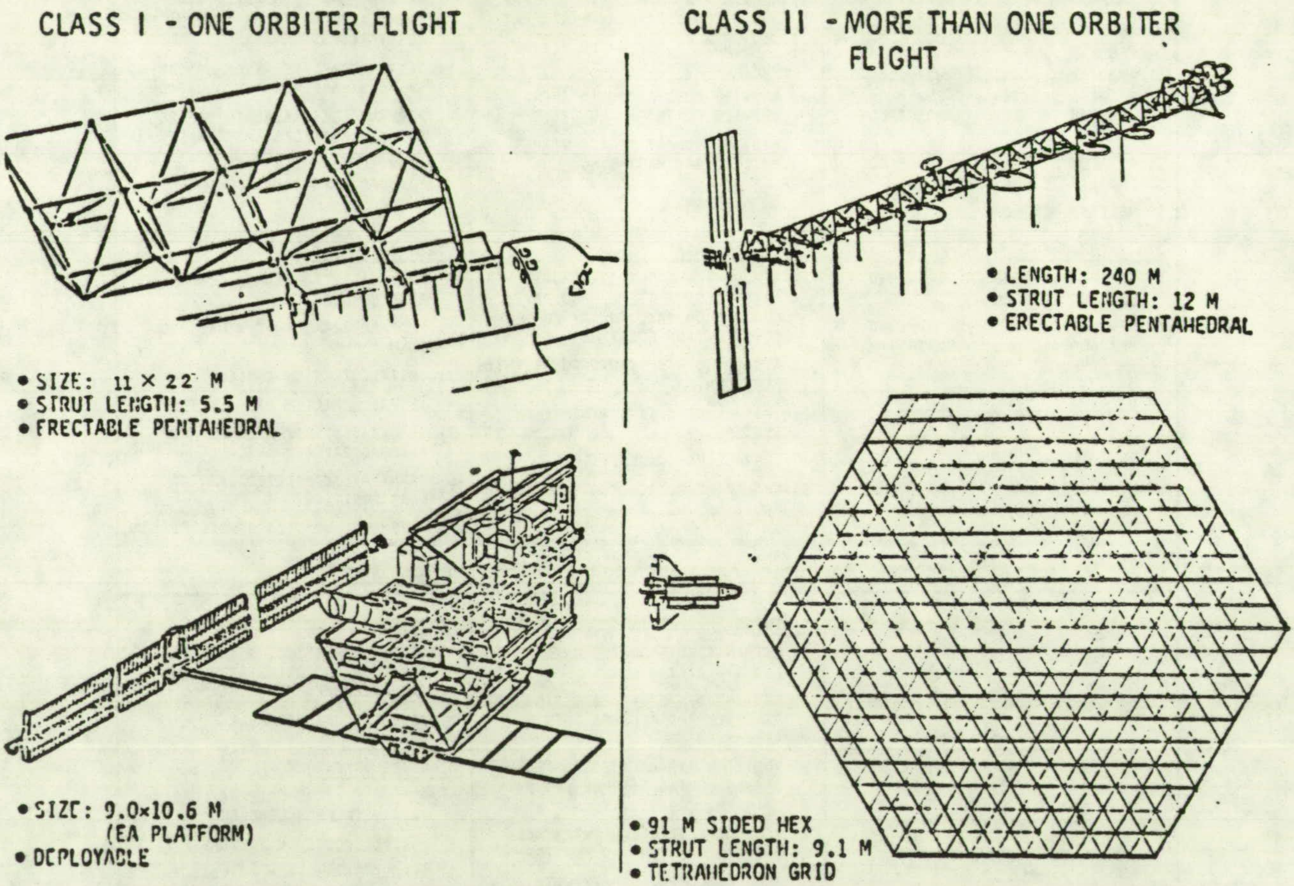


Figure 3.2-1. Construction Requirements Definition Platform Selection

For each platform, a matrix of construction activities versus equipment requirements (see Tables 3.2-1 through 3.2-4) was generated. This matrix defined the construction activity, fixture requirements (including orbiter and platform interfaces), visual aids, and other equipment required (i.e., RMS cherry picker, etc.). Commonality of requirements for construction fixtures for all platforms (Table 3.2-5) included: (1) platform secure/release capability, (2) platform translation, (3) provision for electrical interface—orbiter to platform, (4) indicating sensors for operations (deployment, capture, etc.), and (5) lighting and TV installations. The fixture requirements analysis also pointed out

Table 3.2-1. *Construction Activities and Equipment Requirements, Class I—Deployable Structures*

ACTIVITIES	CONSTRUCTION FIXTURE REQUIREMENTS: INTERFACE: ORBITER	PLATFORM	MECHANICAL REQUIREMENTS	ELECTRICAL REQUIREMENTS	VISUAL AIDS	OTHER EQUIPMENT REQUIRED
1. ACTIVATE ORBITER BERTHING ADAPTER (OBA) POWER AND CONTROL CIRCUITS	A) FIXTURE TO ORBITER ELECTRICAL CONNECTION—WIRE TRAY @ X_o 582 B) STRUCT. ATTACH. C) RH & LH LONGERON LATCHES ≈ X_o 582	NONE	NONE	ELECTRICAL SYSTEM FOR ASSY OPERATIONS COMPATIBLE WITH ORBITER	NONE	A) ORBITER AFD CONSOLE B) DATA PROCESSING & SOFTWARE SUBSYSTEM (DP&S)
2. RELEASE HOLD-DOWN LATCHES & DEPLOY OBA—VERIFY DEPLOYMENT AND CONFIG. FOR OPERATION	SAME AS ACTIVITY NO. 1	NONE	A) LATCHING MECH. FOR HOLD DOWN B) DRIVE MECHANISMS, 2 ROTATING JOINTS	A) DRIVE MOTORS FOR DEPLOYMENT MECHANISMS, B) INDICATION OF OPER. SENSORS, C) OPERATING LIMIT SWITCHES, D) MOTOR FOR UNLATCHING	NONE	A) ORB. AFD CONSOLE B) DP&S C) ORBITER TV/FLOODLIGHTS
3. REMOVE FOLDED PLATFORM FROM P/L BAY AND INSTALL ON OBA	SAME AS ACTIVITY NO. 1	A) INTERFACE STRUCTURE AND LATCHES, B) ELECTRICAL UMBILICAL, C) FLUID UMBILICAL	A) LATCHES TO CAPTURE & SECURE PLATFORM, B) MECHANISM TO DRIVE UMBILICAL PANEL INTO LOCKED POSITION, C) ROTATIONAL SWIVEL JOINTS FOR FLUID TRANSFER	A) LATCHING DRIVE MOTORS, B) INDICATION OF OPERATION SENSORS, C) 360° ELECTRICAL INTERFACE ROTATION, D) DRIVE MOTORS FOR UMBILICAL PANEL LATCHING	A) CCTV/LIGHTING B) INTERFACE ALIGNMENT TARGET	A) ORB. AFD CONSOLE B) DP&S C) ORBITER TV/FLOODLIGHTS D) RMS WITH SPECIAL END EFFECTOR
4. PERFORM ELECTRICAL C/O OF PLATFORM/OBA INTERFACE	SAME AS ACTIVITY NO. 1	SAME AS ACTIVITY NO. 3	SAME AS ACTIVITY NO. 3	A) SPECIAL TESTER B) ADAPTER CABLES	NONE	ORBITER AFD CONSOLE
5. PERFORM PLATFORM DEPLOYMENT	SAME AS ACTIVITY NO. 1	SAME AS ACTIVITY NO. 3	SAME AS ACTIVITY NO. 3	SAME AS ACTIVITY NO. 1	CCTV/LIGHTING	SAME AS ACTIVITY NO. 2
6. A) PERFORM ELECTRICAL CHECKOUT OF PLATFORM, B) VERIFY FLUID LINE OPERATION	SAME AS ACTIVITY NO. 1	SAME AS ACTIVITY NO. 3	SAME AS ACTIV. NO. 3 PLUS ATTACH. DEVICES FOR RETAINING SPECIAL ELECTRICAL TESTER AND FLUID LINE TESTER	A) SPECIAL ELECTRICAL TESTER, B) SPECIAL FLUID LINE TESTER, C) ADAPTER CABLES	CCTV/LIGHTING	SAME AS ACTIVITY NO. 3
7. REMOVE PALLETS FROM P/L BAY & INSTALL ON PLATFORM (ROTATE ADAPTER TO ENHANCE INSTALLATION)	SAME AS ACTIVITY NO. 1	SAME AS ACTIVITY NO. 3	A) 360° INTERFACE ROTATION IN RELATION TO OBA ASSY, B) ±90° ROTATION OF OBA ASSY ABOUT THE BASE	A) DRIVE MOTORS FOR ROTATION MECHANISMS, B) INDICATION OF OPERATION SENSORS, C) OPERATING LIMIT SWITCHES, D) 360° ELEC. I/F ROTATION	CCTV/LIGHTING	SAME AS ACTIVITY NO. 3
8. DEPLOY UMBILICAL PANELS FROM PLATFORM TO MATE WITH PANELS ON PALLET—VERIFY CONNECTION	SAME AS ACTIVITY NO. 1	SAME AS ACTIVITY NO. 3	SAME AS ACTIVITY NO. 3	SAME AS ACTIVITY NO. 3	CCTV/LIGHTING	SAME AS ACTIVITY NO. 2
9. DEPLOY RADIATOR AND SOLAR ARRAYS	SAME AS ACTIVITY NO. 1	SAME AS ACTIVITY NO. 3	SAME AS ACTIVITY NO. 7	SAME AS ACTIVITY NO. 7	CCTV/LIGHTING	SAME AS ACTIVITY NO. 2
10. RELEASE PLATFORM FROM ORBITER & RETURN OBA TO STOWED POSITION; DEACTIVATE POWER AND CONTROL CIRCUITS	SAME AS ACTIVITY NO. 1	SAME AS ACTIVITY NO. 3	A) MECH. TO RELEASE LATCHES & ELEC. & FLUID UMBILICALS, B) MECH. TO CATCH/RETAIN FIXTURE IN STOWED POSITION IN PAYLOAD BAY	A) MOTORS TO ACTIVATE RELEASE MECHANISMS, B) MOTORS TO ACTUATE LATCH LOCKING MECH., C) INDICATE SENSORS FOR LATCHING & LOCKING	NONE	SAME AS ACTIVITY NO. 2

Table 3.2-2. *Construction Activities and Equipment Requirements, Class I—Area Erectable Structure*

ACTIVITIES	CONSTRUCTION FIXTURE REQUIREMENTS: INTERFACE: ORBITER	CONSTRUCTION FIXTURE REQUIREMENTS: INTERFACE: PLATFORM	MECHANICAL REQUIREMENTS	ELECTRICAL REQUIREMENTS	VISUAL AIDS	OTHER EQUIPMENT REQUIRED
1. ACTIVATE FIXTURE POWER AND CONTROL CIRCUITS	A) FIXTURE TO ORBITER ELECT. CONNECTION—WIRE TRAY @ $X_o \approx 700, 1000, 1200$ B) STRUCTURAL ATTCH TO P/L BAY STRUCTURE	NONE	NONE	ELECTRICAL SYSTEM FOR ASSY OPERATIONS COMPATIBLE WITH ORBITER	NONE	A) ORBITER AFD CONSOLE B) DATA PROCESSING & SOFTWARE SUBSYST. (DP&S)
2. DEPLOY RMS FROM STOWED POSITION TO PROVIDE FIXTURE CLEARANCE DURING ITS DEPLOYMENT AND SUBSEQUENT OPNS	NONE	NONE	NONE	NONE	NONE	A) ORBITER AFD CONSOLE B) ORBITER TV/FLOODLIGHTS C) DP&S
3. DEPLOY ASSY FIXTURE FROM P/L BAY AND CONFIGURE FOR OPNS (INCLUDES OPERATION C/O OF SYSTEM)	SAME AS ACTIVITY NO. 1	UNION LOCATOR/RETENTION MECHANISM	DRIVE MECHANISMS FOR A) DEPLOYMENT ROTATION, B) RAIL TRANSLATIONS (X&Y AXES), AND C) PLATFORM TILT	A) DRIVE MOTORS B) INDICATION OF OPERATION SENSORS C) OPERATING LIMIT SWITCHES	A) CCTV B) FLOODLIGHTS	SAME AS ACTIVITY NO. 2
4. CELL BUILDUP A) TRANSFER CONSTR. MAT'L TO WORK AREA, B) ASSEMBLE STRUTS AND UNITS	SAME AS ACTIVITY NO. 1	SAME AS ACTIVITY NO. 3	A) UNION LOCATORS TO POSITION UNIONS B) RETENTION LATCHES TO HOLD FIXTURE	A) SENSORS TO INDICATE UNIONS ARE CAPTURED & LOCKED B) POWER TO LOCATORS AND LATCHES	A) CCTV B) FLOODLIGHTS	A) ORBITER AFD CONSOLE B) DP&S C) RMS D) ORBITER TV/FLOODLIGHTS
5. TRANSLATE CELLS $\pm X$ & $\pm Y$ TO FACILITATE 8-BAY CONSTRUCTION	SAME AS ACTIVITY NO. 1	SAME AS ACTIVITY NO. 3	A) DRIVE MECHANISM FOR RAIL TRANSLATIONS B) UNION LOCATORS TO POSITION UNIONS C) RETENTION LATCHES	A) RETENTION LATCH RELEASE MOTORS B) SENSORS TO INDICATE UNIONS ARE CAPTURED & LOCKED	SAME AS ACTIVITY NO. 4	SAME AS ACTIVITY NO. 4
6. INSTALL UTILITY DISTRIBUTION SYSTEM	SAME AS ACTIVITY NO. 1	SAME AS ACTIVITY NO. 3	A) RETENTION LATCHES B) DRIVE MECH TO TILT FIXTURE FOR SYSTEMS INSTALLATION C) DRIVE MECH FOR RAIL TRANSLATION	A) DRIVE MOTORS TO TILT FIXTURE AND TRANSLATE RAILS	SAME AS ACTIVITY NO. 4	SAME AS ACTIVITY NO. 4 EXCEPT WITH RMS SPECIAL END EFFECTOR
7. ROTATE PLATFORM TO INSTALL P/L PALLETS	SAME AS ACTIVITY NO. 1	SAME AS ACTIVITY NO. 3	A) RETENTION LATCHES B) UNION LOCATORS	SAME AS ACTIVITY NO. 5	SAME AS ACTIVITY NO. 4	SAME AS ACTIVITY NO. 4
8. INSTALL P/L PALLETS (INCL. ATTACHMENT UTILITY DISTRIB. SYSTEM)	SAME AS ACTIVITY NO. 1	SAME AS ACTIVITY NO. 3	RETENTION LATCHES TO RETAIN PLATFORM	NONE	SAME AS ACTIVITY NO. 4	SAME AS ACTIVITY NO. 4 EXCEPT WITH RMS SPECIAL END EFFECTOR
9. UTILITY DISTRIB/PAYLOAD ELECTRICAL CHECKOUT (CONTINUITY, RESISTANCE, ETC.)	SAME AS ACTIVITY NO. 1	ADAPTER CABLES TO PLATFORM DISTRIBUTION SYSTEM	A) RETENTION LATCHES B) ATTACHMENT DEVICE FOR RETAINING SPECIAL TESTER	A) SPECIAL TESTER B) UNIVERSAL TEST CABLE C) ADAPTER CABLES	SAME AS ACTIVITY NO. 4	RMS WITH SPECIAL END EFFECTOR

Table 3.2-3. *Construction Activities and Equipment Requirements—Class II, Linear Erectable Structure*

ACTIVITIES	CONSTRUCTION FIXTURE REQUIREMENTS: INTERFACE: ORBITER	INTERFACE: PLATFORM	MECHANICAL REQUIREMENTS	ELECTRICAL REQUIREMENTS	VISUAL AIDS	OTHER EQUIPMENT REQUIRED
1) A. DEPLOY/ERECT FIXTURES IN P/L BAY B. ACTIVATE POWER AND CONTROL CIRCUITS C. VERIFY FIXTURE OPERATION	PLATFORM ASSEMBLY FIXTURE (PAF) A) LONGERON ATTACH FITTINGS AT $\sim X_o$ 1140 (BOTH SIDES) B) ELECTRICAL CONNECTION—WIRE TRAY AT $\sim X_o$ 1140	NONE	A) INTERFACE MECHANISM TO CONNECT MAIN BODY OF FIXTURE TO ORBITER-ATTACHED BASE (BERTHING-TYPE DEVICE ON CENTERLINE ORBITER. B) ROTATING MECHANISM TO ROTATE FIXTURE ~90° FROM CENTERLINE ORBITER IN Y-Z PLANE C) TRANSLATING MECHANISM FOR ASSY OPNS.	A) ELECT. SYST. FOR POWER & CONTROL FUNCTIONS B) SENSORS FOR OPNS INDICATIONS C) MOTORS/SOLENOIDS TO OPERATE LATCHING/RETAINING MECHANISMS D) LIMIT SWITCHES FOR ROTATIONAL & TRANSLATION MECHANISMS	NONE	A) ORBITER TV AND FLOODLIGHTS B) RMS C) ORB. AFD CONSOLE D) DATA PROCESSING & SOFTWARE SUBSYSTEM (DP&S) E) MMU (EVA) CHERRY PICKER (OPTIONAL USE)
	STRUT ASSY FIXTURE LONGERON ATTACHED RIGHT SIDE OF ORBITER	NONE	LATCHING MECHANISM WITH RELEASE CAPABILITY TO RETAIN ONE STRUT END DURING RIGIDIZING	A) POWER TO OPERATE LATCHING MECH. B) SENSORS FOR LATCH/UNLATCH INDICATION	NONE	A) ORB. AFD CONSOLE B) DP&S C) ORBITER TV AND FLOODLIGHTS
2. ASSEMBLE PENTAHEDRAL CELLS (BASIC PLATFORM STRUCTURE)	PAF SAME AS ACTIVITY 1	STRUT AND/OR UNION ATTACHMENT MECHANISM DURING ASSY	A) MECHANISM FOR CAPTURE/RETAIN AND RELEASE STRUT AND/OR UNION DURING ASSEMBLY B) TRANSLATING MECH FOR ASSEMBLY OPNS	A) MOTORS/SOLENOIDS TO OPERATE STRUT AND/OR UNION LATCHING MECHANISM B) MOTORS TO DRIVE TRANSL. MECHANISMS C) SENSORS FOR OPNS INDICATIONS D) LIMIT SWITCHES FOR TRANSLATING MECHANISMS	A) CCTV B) FLOODLIGHTS	SAME AS ACTIVITY 1
	STRUT ASSY FIXTURE SAME AS ACTIVITY 1	NONE	SAME AS ACTIVITY 1	SAME AS ACTIVITY 1	NONE	A) RMS B) ORB. AFD CONSOLE C) DP&S D) ORB TV & FLOODLIGHTS
3. INSTALL UTILITY DISTRIBUTION SYSTEM	SAME AS ACTIVITY 1	SAME AS ACTIVITY 2	SAME AS ACTIVITY 2 PLUS: (C) ATTACHMENT MECHANISM FOR UTILITY EQUIP (I.E.,UMBILICALS) CANISTERS	SAME AS ACTIVITY 2	SAME AS ACTIVITY NO. 2	SAME AS ACTIVITY 1
4. ASSEMBLE & ATTACH STRUCTURE & BERTHING ADAPTER FOR: A) SOLAR PWR SYSTEM B) SYS. CONTR. CENTER C) RCS MODULES D) PROPUL. MODULES E) ANTENNAS	PAF SAME AS ACTIVITY 1	SAME AS ACTIVITY 2	SAME AS ACTIVITY 2	SAME AS ACTIVITY 2	SAME AS ACTIVITY NO. 2	SAME AS ACTIVITY 1
	STRUT ASSY FIXT. SAME AS ACTIVITY 1	NONE	SAME AS ACTIVITY 1 PLUS: (B) INCORPORATE CAPABILITY TO LATCH AND RETAIN UNIONS DURING SUBSTRUCTURE BUILDUP	SAME AS ACTIVITY 1	NONE	SAME AS ACTIVITY 1

Figure 3.2-4. *Construction Activities and Equipment Requirements, Class II—Area Erectable Structure*

ACTIVITIES	CONSTRUCTION FIXTURE REQUIREMENTS: INTERFACE: ORBITER	INTERFACE: PLATFORM	MECHANICAL REQUIREMENTS	ELECTRICAL REQUIREMENTS	VISUAL AIDS	OTHER EQUIPMENT REQUIRED
1) ACTIVATE FIXTURE POWER & CONTR CIRCUITS: STRUCTURE ASSY; STRUT ASSEMBLY; KIT ASSEMBLY	ELECTRICAL—WIRE TRAY CONNECT: $\sim X_o$ 700; $\sim X_o$ 1000; $\sim X_o$ 1200	NONE NONE	ALREADY CONNECTED FOR 1ST ORBITER FLIGHT, EVA MAKES INTERFACE CONNECT DURING NEXT CONSTRUCTION FLIGHTS OF SEQUENCE.	POWER TO DRIVE. TRANSLATE MECH., CONTROL FROM AFD OR EVA STATION. POWER TO DRIVE FIXTURE, CONTROL FROM AFD	NONE	A) ORBITER AFD CONSOLE B) DATA PROCESSING & SOFTWARE SUB-SYSTEM (DP&S)
2) DEPLOY RMS FROM STOWED POSITION	STANDARD INSTALLATION, LATCHES, ETC.	NONE	END EFFECTOR FOR GRIPPING STRUTS ($\sim$5" D) & UNIONS ($\sim$12" HEX × 6" DEEP)	STANDARD RMS POWER AND CONTROL	A) AFD WINDOWS B) CCTV	A) ORBITER AFD CONS. B) ORB. FLOODLIGHTS C) DP&S
3) ROTATE PLATFORM STRUCTURE ASSY FIXTURE (PAF) OUT OF P/L BAY, CONFIGURE FOR ASSEMBLY OPERATIONS	PLATFORM MOUNT ON ORB. BAY STRUCT., MECHANICALLY SEPARABLE INTERFACE FOR ON-ORBIT STORAGE	RETRACTABLE UNION RETENTION MECHANISM	FLIGHT SUPPORT LATCHES, SEPARABLE MECHANICAL INTERFACE, UP TO 180° ROTATION OF HINGE IN ORBITER BAY, TELESCOPING STRUCTURE SUPPORT RAILS & EXTENSION RAILS (FOR 30-FT STRUT LENGTH)	POWERED ROTATION MECHANISM, POWERED TRANSLATION MECHANISMS	A) AFD WINDOWS B) CCTV C) EVA CREW	A) EVA OPERATIONS FOR LATCH RELEASE B) ORBITER AFD CONSOLE C) DP&S
4) DEPLOY KIT SUBASSY FIXTURE (KAF)	FIXTURE MOUNTS ATTACHED TO P/L BAY STRUCTURE	NONE	FLT SUPPORT LATCHES, MANUALLY OPERATED. FIXTURE PROVIDES FOR UNION CLAMP AND STRUT BALL-END RETENTION DURING KIT BUILDUP, ROTATION OF PARTIALLY ASSEMBLED KIT, FIXTURE MOUNTS ON STRUCTURAL ASSEMBLY FIXT. (ITEM 3)	NONE	A) EVA CREW B) CCTV	A) RMS B) ORB. FLOODLIGHTS C) AFD CONSOLE
5) PREPARE STRUT ASSY FIXTURE (SAF) FOR STRUT UNFOLDING & DELIVERY TO KIT FIXTURE AREA	FIXTURE MOUNT COLUMN ATTACHED TO P/L BAY STRUCTURE LOCATION $\sim X_o$ 1100		FLT SUPPORT LATCHES, MANUAL OPERATION. BASE ROTATION (90°). ELBOW ROTATION $\sim$45°. TELESCOPIC STRUT EXTRACTION DEVICE, END TRAVEL $\sim$6 METERS. EXTRACTION DEVICE ROTATION $\sim$40°. EXTR. DEVICE END EFFECTOR GRASP AND ROTATION OF HINGED STRUT TO UNFOLD INTO RIGID STRUT, 90° EA. STRUT HALF. STRUT ASSY FIXT. PROVISION FOR RETENTION AND SINGLE STRUT ADVANCEMENT OF STRUT STACK.	POWER FOR BASE (SHOULDER) ROTATION (90°), ELBOW ROTATION ($\sim$45°), POWER FOR TELESCOPIC STRUT EXTRACTION DEVICE EXTENSION AND ROTATION	A) AFD WINDOWS B) CCTV	A) RMS B) ORB. FLOODLIGHTS C) AFD CONSOLE

Table 3.2-4. Construction Activities and Equipment Requirements, Class II—Area Erectable Structure (Cont.)

ACTIVITIES	CONSTRUCTION FIXTURE REQUIREMENTS: INTERFACE: ORBITER	CONSTRUCTION FIXTURE REQUIREMENTS: INTERFACE: PLATFORM	CONSTRUCTION FIXTURE REQUIREMENTS: MECHANICAL REQUIREMENTS	CONSTRUCTION FIXTURE REQUIREMENTS: ELECTRICAL REQUIREMENTS	CONSTRUCTION FIXTURE REQUIREMENTS: VISUAL AIDS	OTHER EQUIPMENT REQUIRED
6) PERFORM STRUT ASSY; RMS MOVES NESTED STRUT STACK FROM STORAGE TO THE STRUT ASSY FIXTURE; SAF RETRACTS STRUT FROM STACK AND UNFOLDS TO OPERATIONAL CONFIG.	STRUT STACK STORAGE, SAF ATTACHMENT, RMS FOR TRANSFER OF STRUT STORAGE STACKS TO STRUT ASSY FIXTURE	NONE	STRUT STORAGE FLIGHT RETENTION MECHANISMS, DRIVE MECHANISMS FOR THE SAF OPERATIONS (SEE ITEM 5).	RETENTION RELEASE MECHANISM POWER & CONTROLS, POWER FOR STRUT ASSEMBLY FIXTURE MECHANISMS	A) AFD WINDOWS B) CCTV	A) AFD CONSOLE B) RMS C) ORBITER FLOODLIGHTS
7) PRODUCE "KIT" SUBASSEMBLIES, RMS MOVES STRUTS FROM SAF TO KAF, RMS DELIVERS UNION TO KAF, KAF COMPLETES KIT ASSEMBLY.	KIT ASSEMBLY FIXTURE (KAF) MOUNT, RMS	NONE	KAF STRUT AND UNION RETENTION MECHANISMS, FIXTURE ROTATION MECHANISM	POWER & CONTROLS FOR MECHANISM OPERATIONS	A) AFD WINDOWS B) CCTV	A) AFD CONSOLE B) RMS C) ORB. FLOODLIGHTS D) DP&S
8) PERFORM PLATFORM & UTILITY SEGMENT ASSY. RMS TRANSLATES KITS & INDIVIDUAL STRUTS TO PAF, PAF GRIPS UNIONS, RMS COMPLETES STRUT-TO-UNION CONNECTIONS AS REQUIRED. INSTALL UTILITY DISTRIBUTION SEGMENTS AS REQUIRED.	PAF MOUNT ON ORBITER, RMS	UNION RETENTION MECHANISMS	UNION RETENTION MECHANISM OPERATION	POWER & CONTROL FOR UNION RETENTION MECHANISMS, SENSORS FOR UNION CAPTURE INDICATION	A) AFD WINDOWS B) CCTV	A) AFD CONSOLE B) RMS C) ORB. FLOODLIGHTS D) DP&S
9) TRANSLATE PLATFORM TO NEXT ASSY POSITION. ASSY FIXTURE PROVIDES POWER DRIVE & UNION RETENTION DURING THE TRANSLATE OPERATION.	PAF MOUNT	UNION RETENTION MECHANISMS, PAF RAIL GUIDES	TRANSLATION DRIVE MECHANISM, UNION RETENTION MECHANISMS	POWER & CONTROL FOR TRANSLATION DRIVE MECHANISM, SENSORS FOR TRANSLATION DISTANCE INDICATION, POWER FOR UNION RETENTION MECHANISM RELEASE & UNION GRIP AFTER TRANSLATION TO NEW LOCATION	A) AFD WINDOWS B) CCTV	A) AFD CONSOLE B) DP&S
10) INSTALL PLATFORM STABILIZATION MODULE. TEMPORARY MODULE ATTACHED TO PARTIALLY ASSEMBLED STRUCTURE TO STABILIZE PLATFORM FOR REDOCKING NEXT ORBITER FLIGHT FOR CONTINUING CONSTRUCTION	MODULE STORAGE	MODULE ATTACHMENT INTERFACE	MODULE ATTACHMENT MECHANISM	MODULE CONTROL SYSTEM CHECKOUT WIRING	A) AFD WINDOWS B) CCTV	A) RMS B) AFD CONSOLE C) ORB. FLOODLIGHTS D) DP&S
11) DEACTIVATE FIXTURES FOR ORBITER RETURN FLT. PAF REMAINS ATTACHED TO PARTIALLY COMPLETED PLATFORM. FOLD OTHER MECHANISMS INTO ORBITER BAY, ATTACH FLIGHT RESTRAINTS.	PAF SEPARATION INTERFACE, SAF & KAF ATTACHMENT TO ORBITER	PAF-TO-ORBITER SEPARATION INTERFACE	SEPARATION MECHANISM FOR PAF. KAF SAME AS ITEM 4, SAF SAME AS ITEM 5.	POWER & CONTROLS FOR PAF SEPARATION MECHANISM. SENSORS FOR SEPARATION MECH. KAF SAME AS ITEM 4; SAF SAME AS ITEM 5.	A) AFD WINDOWS B) CCTV	A) RMS B) AFD CONSOLE C) DP&S

Table 3.2-5. *Commonality of Fixture Requirements*

CONSTRUCTION FIXTURE AND INTERFACE REQUIREMENTS	CLASS I AREA ERECTABLE	CLASS I DEPLOYABLE	CLASS II LINEAR ERECTABLE	CLASS II AREA ERECTABLE
PLATFORM SECURE/RELEASE	✓	✓	✓	✓
PLATFORM TRANSLATION (X,Y,Z DIRECTION)	✓	✓	✓	✓
PLATFORM ROTATION (DURING CONSTRUCT.)		✓	✓	
ELECTRICAL INTERFACE—ORBITER TO PLATFORM	✓	✓	✓	✓
EVA CREW AIDS	✓		✓	✓
LIGHTING, TV INSTALLATIONS	✓	✓	✓	✓
FLUID TRANSFER—ORBITER TO PLATFORM		✓		
INDICATOR INSTR.—DEPLOY, CAPTURE, RELEASE, STOW	✓	✓	✓	✓
VISUAL AIDS FOR BERTHING		✓	✓	✓
PLATFORM/FIXTURE LIBRATION DAMPING			✓	✓
RENDEZVOUS AND DOCKING CAPABILITY			✓	✓
SUBASSEMBLY FIXTURES (STRUTS, KITS)			✓	✓
FIXTURE/ORBITER INTERFACE SEPARATION			✓	✓
ON-ORBIT STORAGE FOR ASSEMBLY AIDS			✓	✓

the impact that size and shape of the platforms have on the construction fixture. For example, the large area platform requires additional construction equipment to assemble as compared to the small area platform or the linear platform where the RMS reach is more effective. Additionally, installation of systems (utility distribution) and payloads can be drivers in the design of the fixture insofar as reaching to distant points of a platform to install or service a system may require rotation or tilting of the platform for accessibility.

It is of interest to estimate construction time comparisons for the platforms considered. A rough order of magnitude (ROM) analysis was made of the estimated time required to assemble the structure and attach utility lines to the structure (where applicable) for each of the platforms shown in Figure 3.2-1. The time estimate was based on the operational activities shown on Tables 3.2-1 through 3.2-4 and use of the construction equipment listed on the same tables. A chart summarizing pertinent structural assembly comparison factors is shown in Table 3.2-6. Total platform activation times resulting from the analyses are given in Table 3.2-7. Further details of the time estimation methodology are given in Appendix C.

3.3 CONSTRUCTION OPERATIONS PARAMETRIC ANALYSIS

Another approach taken in determining the design requirements for the construction fixture was by means of a parametric analysis. The analysis combines the RMS capability with fixture capability/complexity to determine the size and configuration of the space platforms that can be assembled. Three variations

Table 3.2-6. *Structure Assembly Comparison Factors*

FACTOR	PLATFORM A ERECTABLE SCIENCE & APPLIC. PLATFORM	PLATFORM B DEPLOYABLE SCIENCE & APPLIC. PLATFORM	PLATFORM C ERECTABLE ADV. TECHNOLOGY PLATF. (LINEAR)	PLATFORM D ERECTABLE TETRAHEDRAL AREA PLATF.
PLATFORM DIMENSIONS (METERS)	11×22	TWO 9.3×11.0	12×240	91 M HEX SIDES (~158×182)
PLATFORM PLAN AREA	242 M^2	205 M^2	2880 M^2	21,734 M^2
NO. OF COMPONENTS IN STRUCTURE ASSEMBLY	17 KITS 18 STRUTS	TWO DEPLOYABLE ASSEMBLIES	62 UNIONS 160 STRUTS	300 KITS 331 UNIONS 870 STRUTS
NO. P/L PALLET POSITIONS (FACING SAME DIRECTION)	15 AT 5.5-M CENTERS	12 AT 5.5-M CENTERS (4 OPPOSITE)	N/A	80 AT 18.3-M CENTERS (331 AT 9.1-M CENTERS)
PLATFORM "CELL" FORMAT	PENTAHEDRAL 5.5-M STRUTS	SQUARE FACE WEDGE ~4.9 & 11.0 M DEPLOYED STRUTS	PENTAHEDRAL 12-M STRUTS	TETRAHEDRAL 9.1-M STRUTS
PLATFORM ASSEMBLY FIXTURES & TOOLS	RMS ASSEMBLY FIXTURE	RMS, BERTHING ADAPTER	RMS, ASSEMBLY FIXTURE, STRUT ASSY DEVICE	RMS, ASSY FIXTURE, STRUT ASSY DEVICE, KIT ASSY FIXTURE
NO. "CELLS" PER PLATFORM	8	12	20	300
PLATFORM CELL TRANSLATION DURING ASSEMBLY	RMS	BERTHING ADAPTER	ASSY FIXTURE POWER DRIVE	ASSY FIXTURE POWER DRIVE

Table 3.2-7. Platform Construction Timeline Comparisons

ITEM	ACTIVITY	TIME ESTIMATES, MINUTES (HOURS)			
		PLATFORM A	PLATFORM B	PLATFORM C*	PLATFORM D**
1	PREPARE CONSTRUCTION FIXTURES	60 (1.00)	N/A	120 (2.00)	450 (7.50)
2	AVERAGE ASSEMBLY TIME PER BAY	54 (0.90)	N/A	137 (2.28)	83 (1.38)
3	BAYS PER PLATFORM	8	16	20	300
4	TOTAL STRUCTURE ASSEMBLY TIME	432 (7.20)	N/A	2740 (45.67)	2490 (415.0)
5	UTILITY SYSTEM INSTALLATION (INCLUDES ATTACH TO POWER MODULES, ETC.)	434 (7.23)	N/A	1299 (21.65)	2784 (46.40)
6	TOTAL STRUCTURE ASSEMBLY, UTILITY SYSTEM INSTALLATION	926 (15.43)	660 (11.00)	4039 (67.32)	27,684 (461.4)
7	SYSTEMS CHECKOUT	180 (3.00)	360 (6.00)	600 (10.00)	1200 (20.00)
8	TOTAL PLATFORM ACTIVATION TIME	1106 (18.43)	1020 (17.00)	4759 (79.32)	29,334 (488.9)

*ASSUMES 2 ORBITER FLIGHTS

**ASSUMES 5 ORBITER FLIGHTS

of construction operations were defined, each of which utilized a varying degree of fixture capability/complexity. The construction operations were categorized as Segment A, Segment B, and Segment C (Figure 3.3-1).

Segment A defines a construction operation whereby the space platform is constructed in one orbiter flight. It utilizes a fixture that is deployed from the payload bay with rotational capability on all joints as well as the interface. It does not provide translational capability in any axis.

Segment B defines a construction operation similar to Segment B (platform is constructed in one orbiter flight) and utilizes the same fixture as Segment A. Segment B, however, in order to be able to construct a larger space system, incorporates a translating rail system which, when attached to the deployed fixture, brings additional working area within the RMS capability.

Segment C defines a large space system construction operation that requires more than one orbiter flight to accomplish. It utilizes the fixture concept of Segment B with the exception of the rail system. Constructing a larger space system necessitates a larger rail fixture, the incorporation of capability for untended operations (stability control), and the capability for orbiter return and docking operations.

3.3.1 Operational Factors

For purposes of this analysis, the construction fixture requirements were based on utilizing the full capability of the RMS for construction of the platforms without the aid of EVA. To accomplish these types of operations, it was necessary to maintain the work station within the workable RMS reach envelope.

Limits of the RMS reach capability are shown in Figures 3.3-2 through 3.3-4. The limits shown are actually contours with respect to the axis that is orthogonal to the plane of the paper. The contours shown do not take into account an orbiter/RMS interference; therefore, the total reach accessibility within the contour envelopes may not be available. Distances in the X, Y, and Z axes are measured from the RMS shoulder pivot point. These figures have been extracted from document JSC 07700, Volume XIV, *Space Shuttle System Payload Accommodation, Level II Program Definition and Requirements.*"

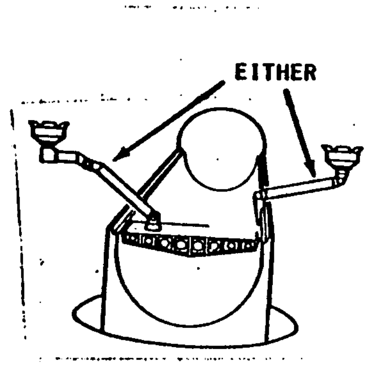
In addition, maintaining the work station within the operator's FOV was preferred. This requirement was not a constraint, however, in that use of the RMS-mounted TV, the orbiter-mounted TV and, if necessary, the use of TV mounted on the fixture would be used for construction operations. Flexibility in TV mounting locations is available on the orbiter with TV pan/tilt capability available on the RMS.

3.3.2 Payload Bay Installation

Location of the fixture in the orbiter payload bay was determined by the RMS reach envelope and stowage considerations. Detailed analyses of platform/fixture/RMS relationship can be found in Appendix B. It is assumed, for this study, that EVA egress/ingress from the crew compartment would be required even though there is no requirement for EVA during construction. Contingency

SEGMENT A CONSTRUCTION OPERATIONS

- SINGLE ORBITER MISSION TO COMPLETE ASSEMBLY
- NO REBERTHING/TRANSLATION REQUIRED

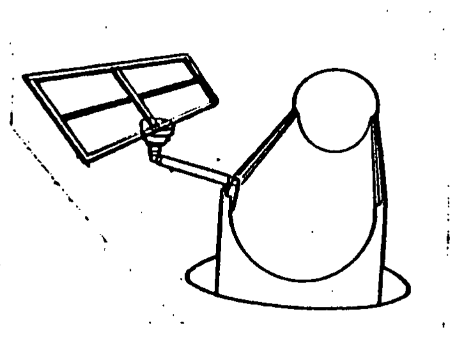


A-TYPE FIXTURE

- DEPLOYED FROM PAYLOAD BAY
- JOINT ROTATION
- INTERFACE ROTATION (± 180°)

SEGMENT B CONSTRUCTION OPERATIONS

- SINGLE ORBITER MISSION TO COMPLETE ASSEMBLY
- REBERTHING/TRANSLATION

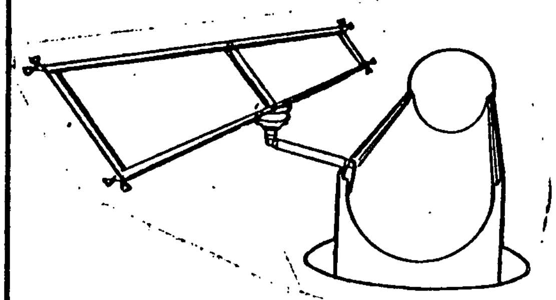


B-TYPE FIXTURE

- SEGMENT A PLUS TRANSLATION RAILS

SEGMENT C CONSTRUCTION OPERATIONS

- MULTIPLE ORBITER MISSIONS TO COMPLETE ASSEMBLY
- ORBITER REDOCKING CAPABILITY



C-TYPE FIXTURE

- SEGMENT B EXCEPT LARGER RAIL FIXTURE
- FIXTURE STAYS WITH PLATFORM
- REDOCKING CAPABILITY

Figure 3.3-1. Construction Operation Concepts

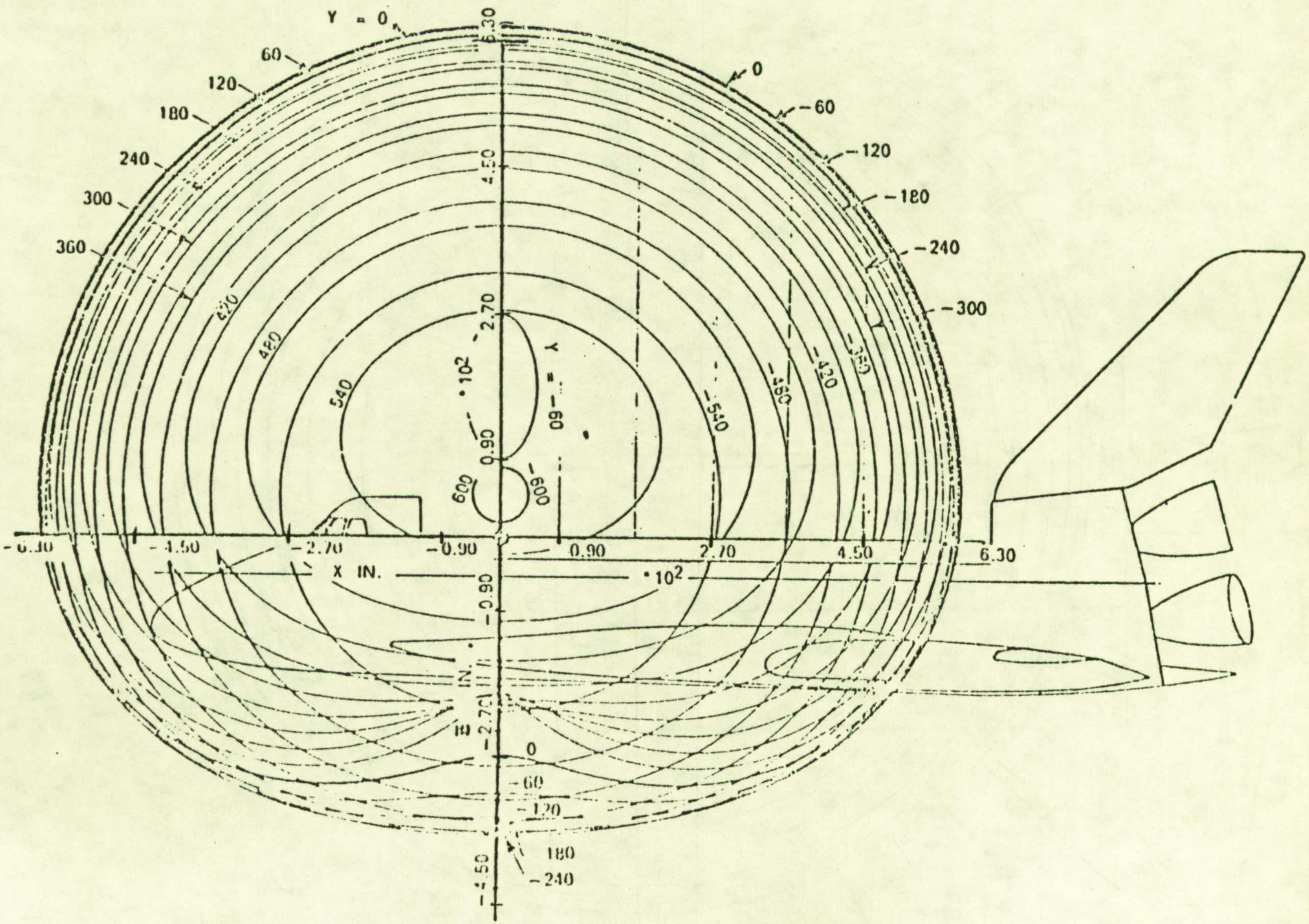


Figure 3.3-2. Side View of Orbiter and RMS Reach (Y-Contours)

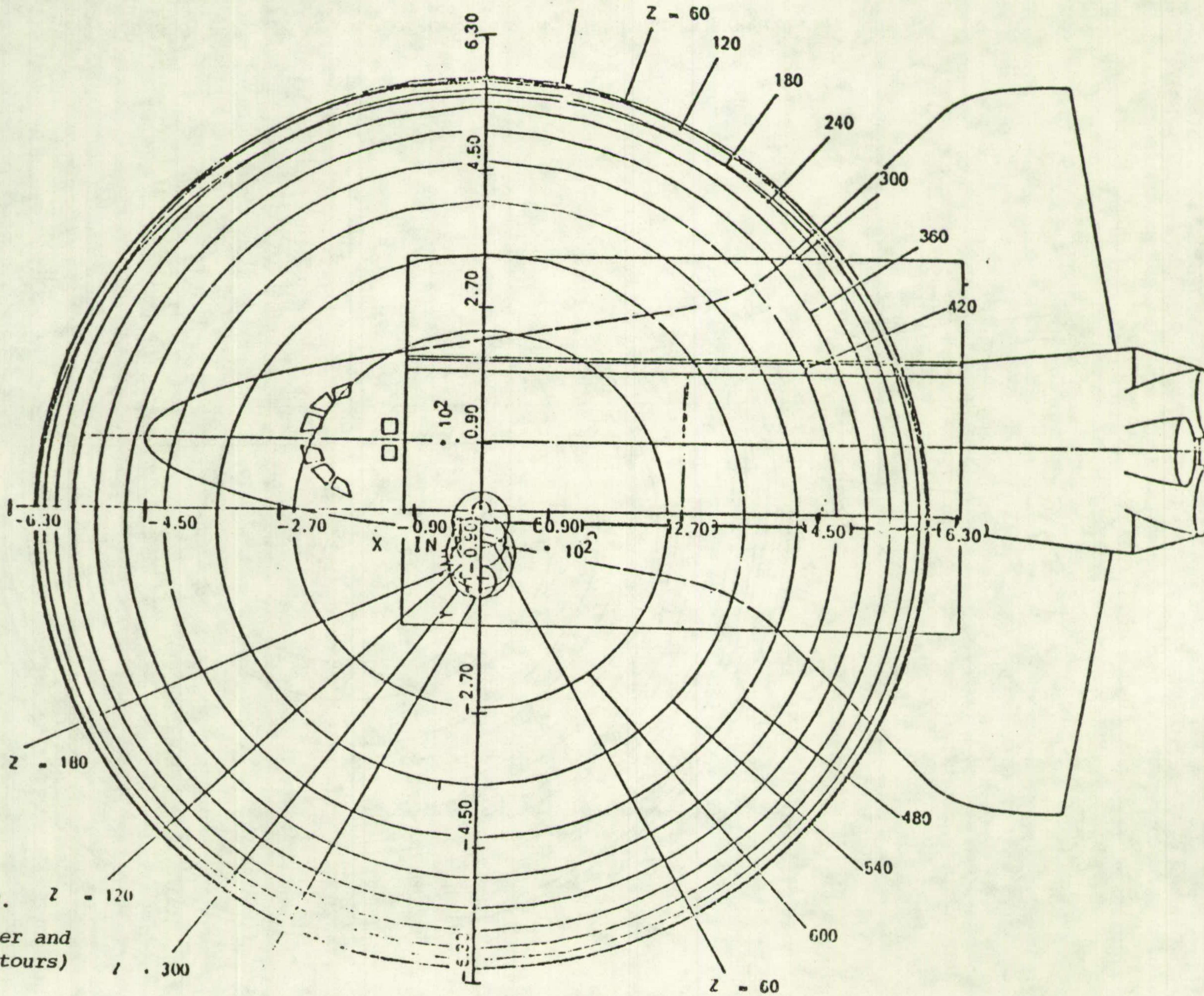


Figure 3.3-3.

Top View of Orbiter and RMS Reach (Z-Contours)

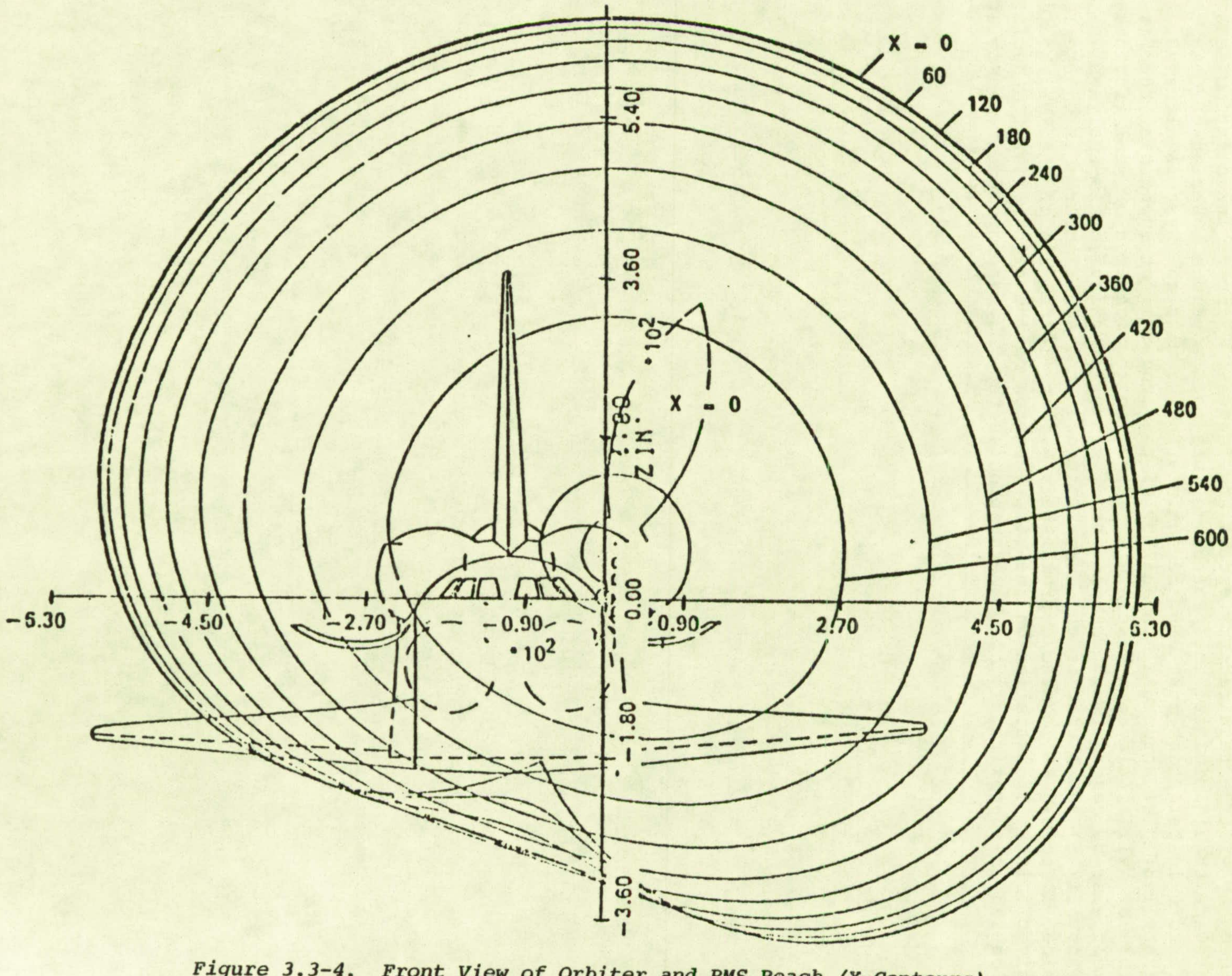


Figure 3.3-4. Front View of Orbiter and RMS Reach (X-Contours)

operations requiring EVA must be planned. The EVA airlock will be within the crew compartment and, as such, only an EVA reserved area envelope in the payload bay will be required for egress and ingress. Fixture installation and stowage should minimize the protrusion into this envelope. Design of the fixture installation must also be noninterfering with the systems already installed. The structural capability of the longeron for supporting the fixture as well as tie-down restraints, either on the longeron or keel fittings, must also be considered. The platform/fixture/RMS relationship analyses (Appendix B) shows that if the installation on the sill longeron is on the left side, it should be located approximately 4.57 m (15 ft) aft of the RMS shoulder pivot point. If installed on the sill longeron on the right side, it should be located at approximately the same station as the RMS, or forward if possible.

4.0 CONSTRUCTION FIXTURE DESIGN

4.1 GENERAL

The fixture requirements analysis previously completed in this study has shown that space platforms can be constructed from the orbiter bay, utilizing the RMS in construction with an assembly fixture and aids. In order to perform the construction operations in this automated mode, the fixture/aids must be designed to maintain the work station within the RMS reach capability. General requirements imposed on the fixture design to accomplish this task include the following.

1. All platforms will not be the same size or configuration and may be deployable, erectable or hybrid (combination of both), thereby requiring the design of a "base" fixture with the capability for combining ancillary equipment/fixtures to accommodate these variations.

2. The fixture must be designed to provide clearance (fixture and platform) with the orbiter outer mold line during construction operations.

3. Freedom of rotation (pitch, yaw, roll) and translation (X_O, Y_O axes) is required to bring the construction area to within the RMS reach.

4. The location of the fixture within the payload bay should minimize the use of the payload volume, provide RMS/fixture compatibility, and limit disruption of payload volume continuity.

As stated previously in the parametric analysis, three segments of construction operations were chosen for fixture design evaluation. For purposes of design, the fixture required for Segment A operations will be the "base" fixture with the ancillary fixtures/aids required to accommodate Segments B and C operations.

4.2 BASE FIXTURE

Two construction fixture concepts—Concepts A and B—were developed from the requirements generated through the analysis portion of this study. See Appendix E for concept layouts. Both concepts satisfy the requirements for Segment A construction, with the capability for adding additional structure to achieve Segment B and Segment C construction. They are both deployable from the payload bay and each utilizes some portions of hardware presently being developed for space operations. In addition, the interfacing portion of the fixtures (latches, electrical connectors, structure) are common to both concepts. The basic difference in the concepts is the method of installation and stowage in the payload bay.

4.2.1 Concept A (Figure 4.2-1)

Figure 4.2-1 is extracted from Design Drawing 42537-131, which is included in Appendix E (p. E-3). This fixture is designed to be installed on the orbiter sill longeron and incorporates the rotating actuator and longeron structural attachment presently being developed for the payload installation and deployment aid (PIDA). The PIDA is a mechanism designed by the NASA at Johnson Space Center, Houston, Texas, to aid the RMS in deploying and installing payloads from the payload bay. For stowage during launch and transportation, the fixture is rotated into the payload bay and retained by a structural attachment to an orbiter keel fitting. Concept A can be installed in an X_o location on the longeron on either the port or starboard side of the orbiter. From the RMS/fixture compatibility analysis it is shown than an X_o 880 on the port longeron, or X_o 630 on the starboard longeron, is preferred.

The principal reason for the 21-ft (6.4-m) further aft location on the port installation is the limitation on RMS operations in close proximity to the base (shoulder) of the RMS. Related factors that limit the specific locations of the fixture attachments include avoidance of the orbiter door hinges, the RMS retention clamp support pedestals, the radiator electrical power and coolant line crossover loops, and the availability of the structural mid-body attach points.

In the starboard location the EVA reserved egress/ingress envelope is violated during launch. However, when the fixture is deployed, only a small portion of the envelope is affected and this is not considered detrimental. Figure 4.2-2(a) shows the required envelope for stowing the fixture installed on the port longeron, and Figure 4.2-2(b) shows the required envelope for stowing the fixture installed on the starboard longeron superimposed on the EVA reserved area envelope.

4.2.2 Concept B (Figure 4.2-3)

This fixture is designed to be installed on a structural beam that spans the payload bay near the forward bulkhead. The beam itself is retained by the longeron trunnion fittings like a payload pallet, the forward-most attach point available being at $X_o = 616.67$. Although the beam is located in the area reserved for EVA egress/ingress from the internal airlock, it is felt that the infringement is not enough to warrant moving the beam location further aft, thus reducing available payload volume. Figure 4.2-4 shows the EVA reserved area envelope superimposed by the envelope required for the fixture. It is anticipated that the design of the shoulder and elbow joints (actuators, drive mechanisms, etc., including the separation system) presently incorporated in the RMS would be used in the design of this fixture.

4.2.3 Concept Evaluation

A summary of the evaluation of the two fixture concepts is found in Table 4.2-1. It is based on the data generated during the preparation of the conceptual layouts (Appendix E) as well as incorporating the fixture requirements previously defined. Using these summary data, the advantages and disadvantages of each concept were outlined as shown in Table 4.2-2. The basic drivers in selecting the design for a base fixture were (1) payload bay stowage (payload volume limitation), and (2) weight.

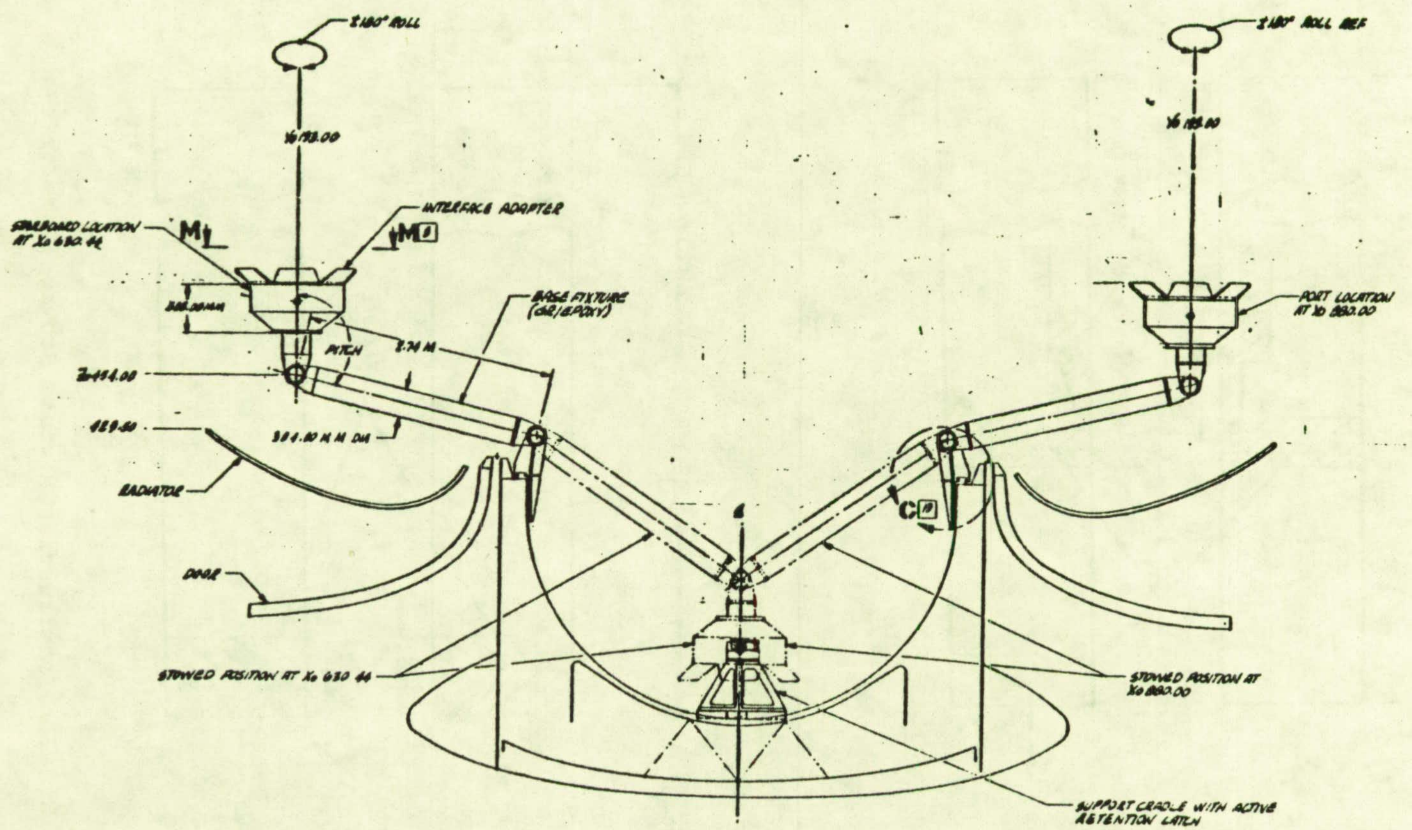


Figure 4.2-1. Base Fixture—Concept A

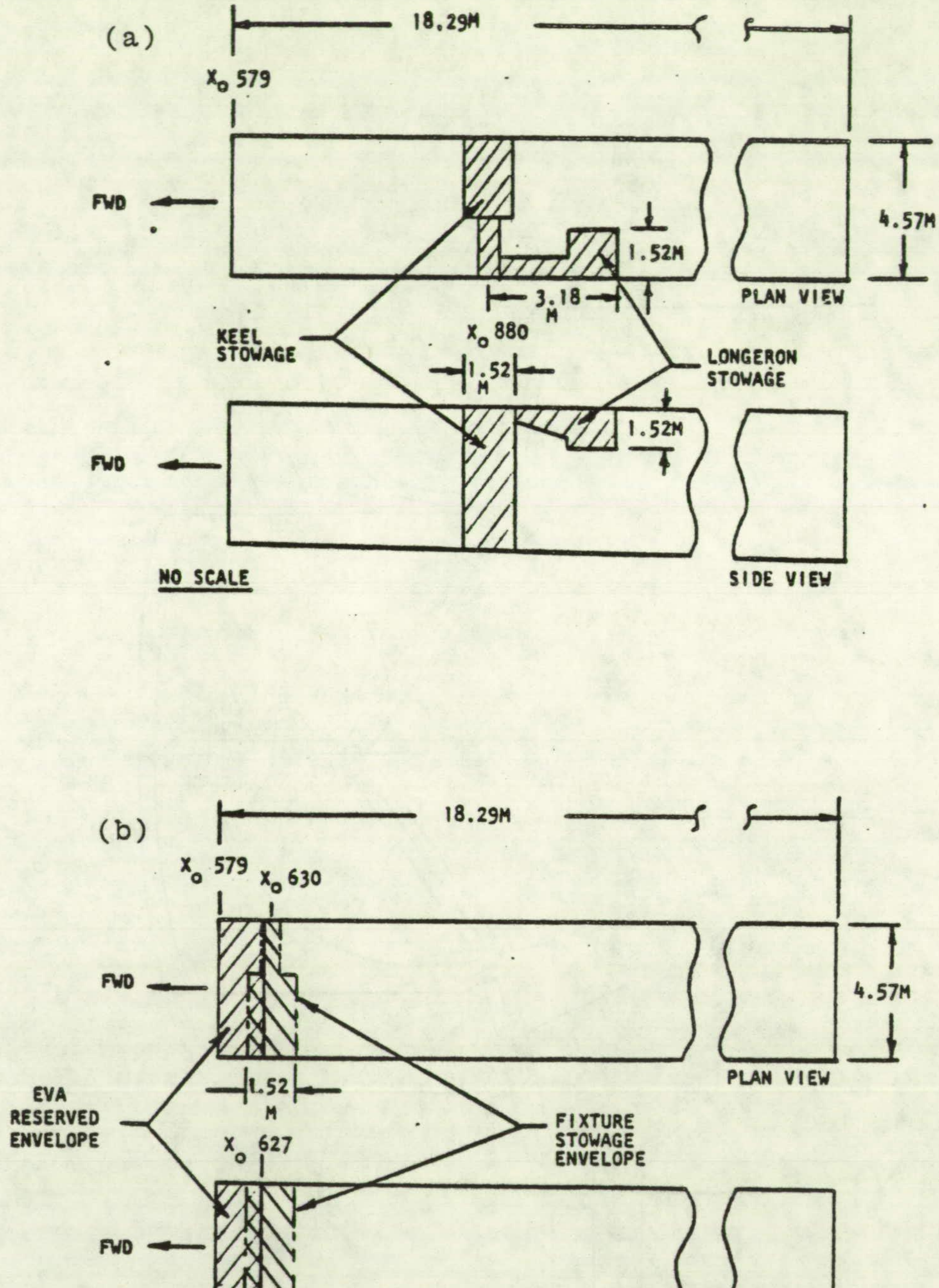


Figure 4.2-2. Construction Fixture Stowage Envelopes

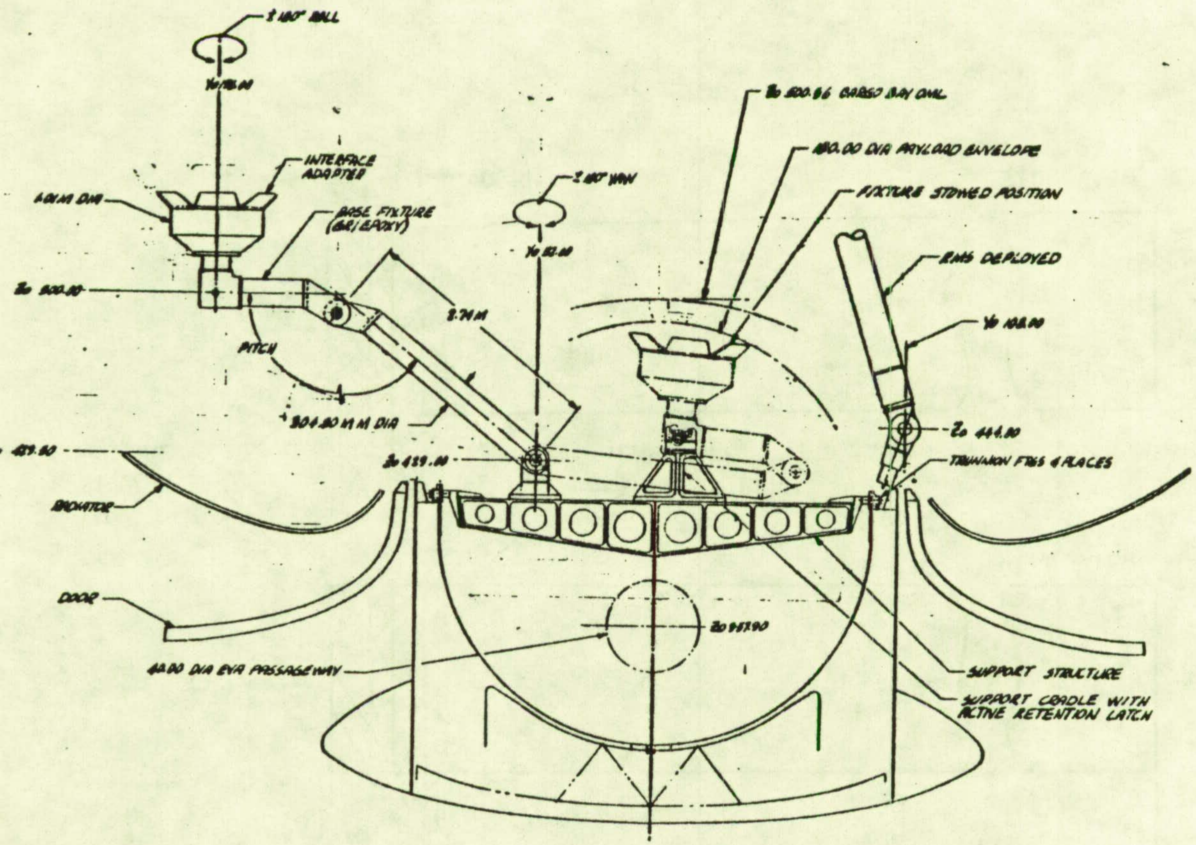


Figure 4.2-3. Base Fixture—Concept B

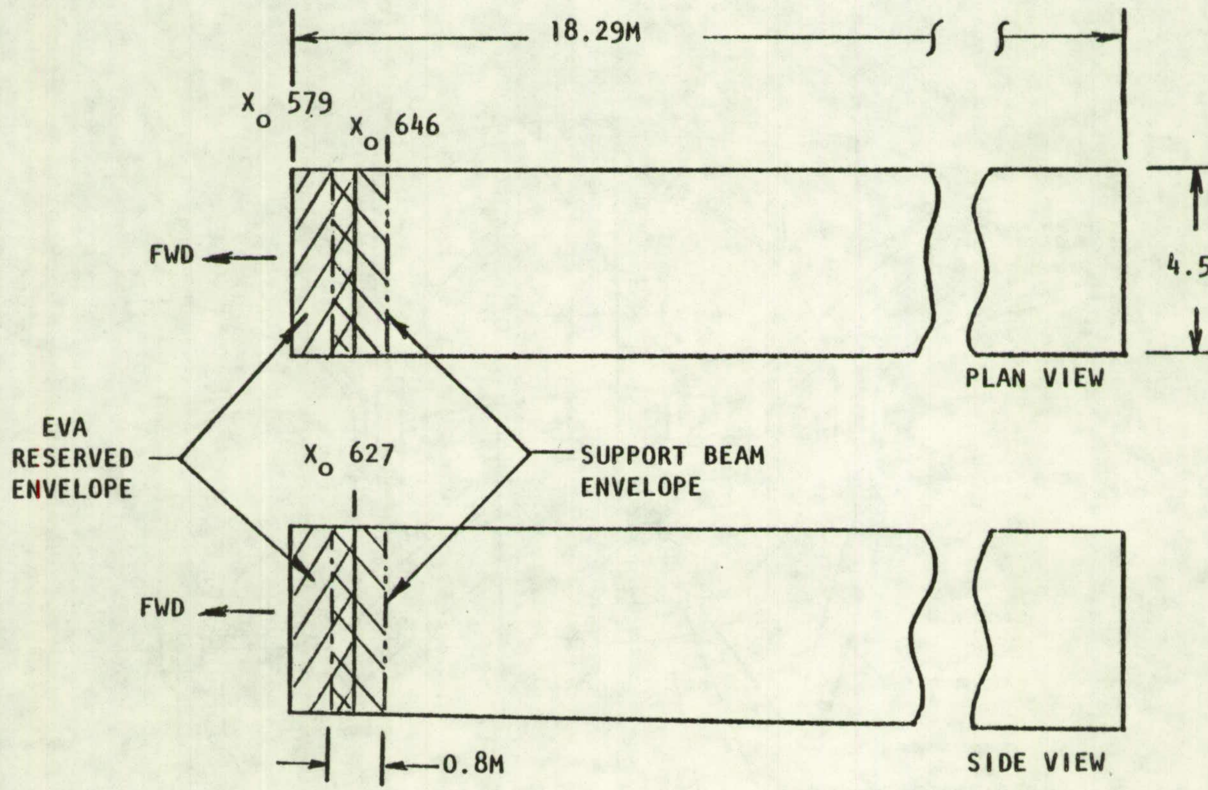


Figure 4.2-4. Construction Fixture Support Beam Envelope

Table 4.2-1. *Summary Evaluation of Base Fixture Concepts*

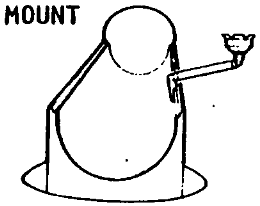
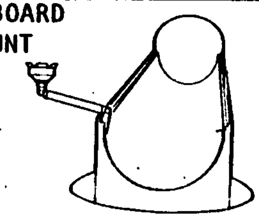
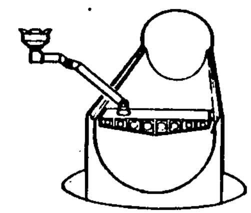
PARAMETER	CONCEPT A		CONCEPT B
	PORT MOUNT  AFT	STARBOARD MOUNT  AFT	 AFT
COMPLEXITY	• KEEL TIE-DOWN ATTACH MAY BE COMPLEX	• KEEL TIE-DOWN ATTACH MAY BE COMPLEX • REQUIRES ADDED TV	• ADDITIONAL DOF IN ATTACHING PIVOT FOR SHOULDER ROTATION • REQUIRES ADDED TV
INSTALLATION IN PAYLOAD BAY	• SIMPLE LONGERON INSTALLATION • STOWAGE TIE-DOWN ATTACH TO KEEL FITTING	• SIMPLE LONGERON INSTALLATION • STOWAGE TIE-DOWN ATTACH TO KEEL FITTING	• REQUIRES SUPPORT BEAM SPANNING P/L BAY—ATTACH TO TRUNNION FITTINGS • LONGERON TAKES LATERAL LOADS
VERSATILITY FOR CONSTRUCTION OPERATIONS	• VERTICAL ELEVATION • TILT • INTERFACE ROTATION	• VERTICAL ELEVATION • TILT • INTERFACE ROTATION	• VERTICAL ELEVATION • TILT • INTERFACE ROTATION • SHOULDER ROTATION • RELOCATION IN BAY DURING FLIGHT FEASIBLE
PAYLOAD BAY VOL. REQMTS	• INTERRUPTS P/L BAY VOLUME ENVELOPE • TRUNNION ATTACH LOCATION REDUCED	• RETAINS 5-PALLET TRAIN CAPABILITY • EVA ENVELOPE VIOLATED BY KEEL FITTING ATTACHMENT	• RETAINS 5-PALLET TRAIN CAPABILITY • EVA ENVELOPE VIOLATED BY SUPPORT BEAM
OPERATIONAL VIEWING DURING CONSTRUCTION	• FULL USE OF OPERATOR'S FOV AND TV	• OUT OF OPERATOR'S FOV AND TV	• OUT OF OPERATOR'S FOV AND TV AS DEPLOYED—SHOULDER ROTATION REQ'D BUT LIMITS PLATFORM SIZE
DEVELOPED HARDWARE UTILIZATION	• PIDA ACTUATION SYSTEM AT SHOULDER JOINT	• PIDA ACTUATION SYSTEM AT SHOULDER JOINT	• RMS ACTUATION AND SEPARATION SYSTEM AT SHOULDER JOINT
WEIGHT	• SHORTER MEMBERS • WEIGHT TO INCLUDE KEEL FITTING AND LONGERON BEEF-UP	• SHORTER MEMBERS • WEIGHT TO INCLUDE KEEL FITTING AND LONGERON BEEF-UP	• ADDED WEIGHT FOR SUPPORT BEAM • LONGERON FITTINGS REQUIRED

Table 4.2-2. Concept Advantages/Disadvantages Summary

CONCEPT A		CONCEPT B
PORT/MID-BAY MOUNTED	STARBOARD/FORWARD MOUNTED	
ADVANTAGES		
1) OPERATOR'S FOV AND TV AVAILABLE 2) LIGHT WEIGHT 3) SIMPLE LONGERON INSTALLATION	1) LIGHT WEIGHT 2) FIVE-PALLET TRAIN CAPABILITY RETAINED 3) SIMPLE LONGERON INSTALLATION	1) RELOCATION IN BAY CAN BE ACCOMPLISHED IN FLIGHT 2) FIVE-PALLET TRAIN CAPABILITY RETAINED 3) SIMPLE LONGERON INSTALLATION
DISADVANTAGES		
1) STOWAGE IN PAYLOAD BAY INTERRUPTS PAYLOAD LENGTH AND REDUCES NUMBER OF PAYLOAD BRIDGE FITTING ATTACHMENTS 2) KEEL TIE-DOWN ATTACHMENT REQUIRED	1) FIXTURE OUT OF FOV OF OPERATOR AND PAYLOAD BAY TV; ADDITIONAL TV REQUIRED 2) KEEL TIE-DOWN ATTACHMENT REQUIRED	1) HEAVIER - LONGER MEMBERS - SUPPORT BEAM REQUIRED 2) MORE COMPLEX— ADDED DOF 3) FIXTURE OUT OF FOV OF OPERATOR AND PAYLOAD BAY TV; ADDITIONAL TV REQUIRED FOR OPERATIONS

Concept A, mounted on the orbiter port longeron, was considered unacceptable due to the disruption of the payload bay volume envelope and the reduction of available trunnion attach locations. The concept offered a simple, lightweight design; however, the payload volume could not be compromised. Concept A (Figure 4.2-1), mounted on the starboard longeron, was chosen for further detail analysis based primarily on weight (see Appendix D) and simplicity. Both Concepts A and B satisfied the construction requirements and payload volume requirements. However, both require additional TV locations other than that presently allocated in the orbiter bay. Concept B can be brought into the operator's field of view (FOV) and TV viewing by rotating the fixture aft and inboard (using the added DOF gained by shoulder joint rotation). This would provide viewing for construction of small platforms, but would not enhance the construction of large platforms.

4.3 FIXTURE SYSTEM DEFINTION

The construction fixture system developed in this study consists of (1) a base fixture (defined above) incorporating an interface to accept either a platform or additional fixture attachments, (2) two deployable attaching structures (one large, one small) with capability to translate a space platform along one axis during space construction (includes attachment nodes), and (3) a structure/mechanism to support the base fixture during stowage in the payload bay, and (4) construction aids. Refer to Appendix E for drawings and layouts. Figure 4.3-1 illustrates the segments of construction operations.

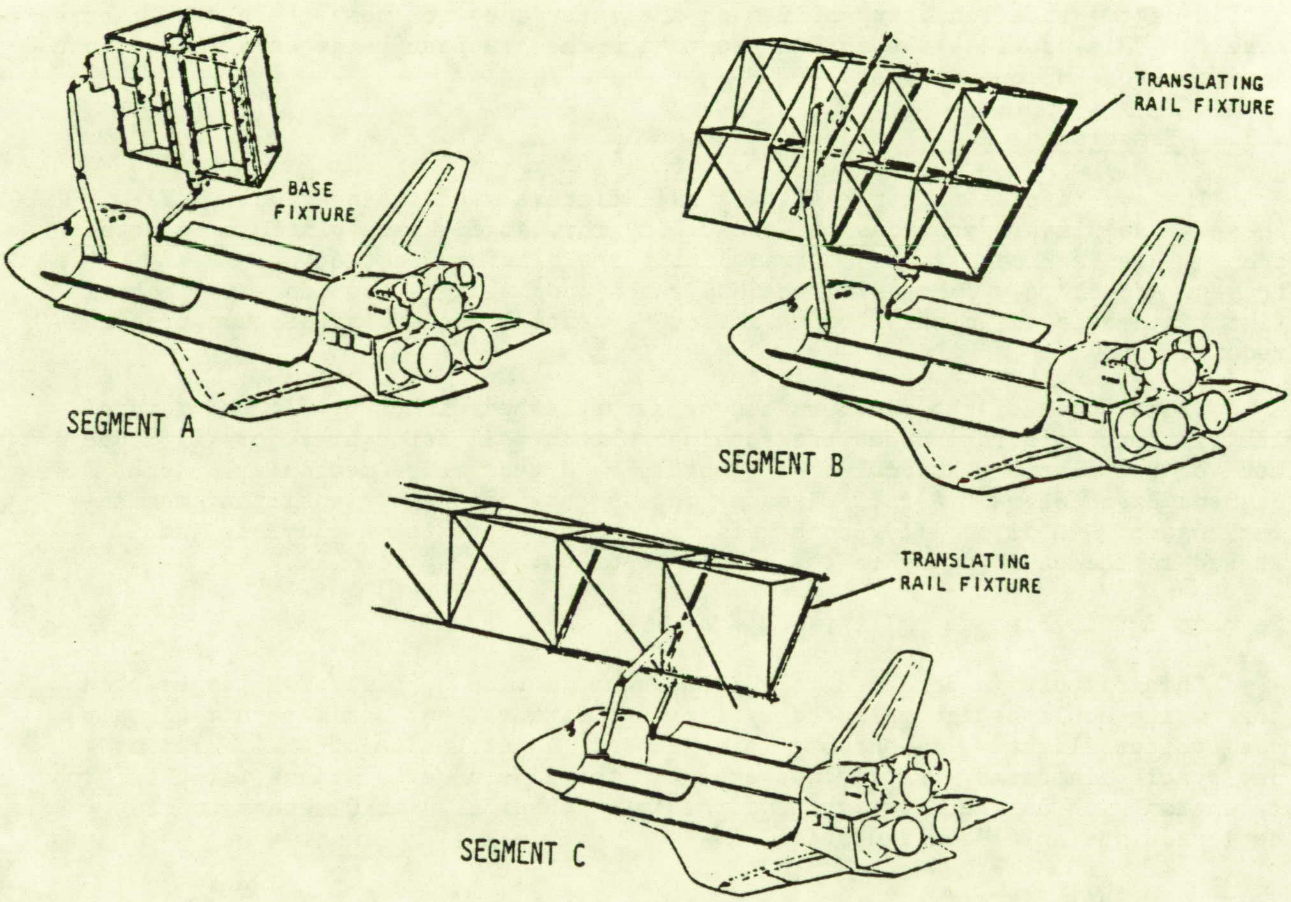


Figure 4.3-1. Construction Fixture Segments of Operation

4.3.1 Base Fixtures

The base fixture is attached to the orbiter sill longeron at X_o 630.4 using the PIDA attaching structure modified to provide additional structural capability. The PIDA rotating actuator will be used to drive the lower attach joint during deployment and return to stow, as well as provide the required joint rotations during construction operations. The additional rotating joint located at the adapter end will be a conventional gear mechanism for a single DOF rotation only.

A portion of the base fixture which provides the physical/structural interface between the translating rail fixture attachment and/or a single platform is defined as the *interface adapter.* It consists of aligning guides, structural latches, and four remotely activated electrical connectors; see Appendix D (p. D-2). The electrical connector installation provides redundant power and data provisions from the orbiter to the translating fixtures during construction and is available to platforms directly installed on the adapter, if needed.

Also included as part of the interface adapter is a mechanism providing a ±180-degree rotational capability of the interface with respect to the fixture itself. This provides the ability to rotate the platform being constructed into position for RMS operations.

4.3.2 Translating Rail Fixtures

The combination of a translating rail fixture with the previously discussed base fixture provides the capability for larger space platform construction. This is accomplished by translating the platform to the work area, thereby effectively increasing the RMS reach capability. Two concepts of rail fixtures developed in this study satisfy Segments B and C platform construction requirements.

Translation of the platform can be accomplished either by (1) RMS moving the platform (platform nodes are retained within rail structure), or (2) movement of the platform accomplished remotely by a gear drive mechanism. Both Segment B and Segment C rail fixtures incorporate the same translating mechanism concept. Additionally, both rail fixture concepts are deployable and stowed in the payload bay in the folded position.

Segment B Rail Fixture

This fixture is designed to support construction of platforms larger than that which could be accomplished by the base fixture, but still requiring only one orbiter flight. Its purpose is to support construction of small area or deployable platforms. Provisions are made for nine node locations for platform retention with an overall length/width dimension of 11.0×11.0 meters in the deployed (operable) configuration.

Segment C Rail Fixture

Unlike the Segment B fixture, this fixture is designed to support construction of large linear erectable platforms requiring multiple orbiter flights. Six node locations for platform retention are provided with an overall length/width dimension of 9.14×18.28 meters in the deployed (operable) configuration. To support untended platform operations, provisions are made to include libration damping capability (RCS), self-sustaining support system (batteries, electrical, heater, etc.), and orbiter return capability (rendezvous radar, lights, etc.). This study did not include concepts for these systems, but merely notes that such systems would be required of any large construction fixture of this kind.

4.3.3 Retention Mechanisms

A mechanism installed in the rail fixture at each node location on the rail fixture serves as a positioning device as well as a retention system for the platform during construction. The mechanism provides the capability to locate the platform on the fixture in its proper position, retain it in that position and, when that area of work is completed, release the platform to allow its translation to another position.

Three configurations (Figure 4.3-2) have been developed in this study to provide this capability; two are designed to interface with strut unions, and one to interface with a strut diameter.

4.3.4 Stowage Provisions

One consideration for the stowage of the base fixture in the payload bay, as shown in this study, is through a structural tie with the orbiter keel fitting structure. As presently designed, the keel fittings can accommodate Y_O and X_O loads only. Therefore, modifications must be made to the keel fitting structural design to accept Z_O loads and moment loading. Actual attachment between the interface adapter and the stowage fitting will use an orbiter active payload trunnion fitting. This fitting will be qualified for orbiter usage and, therefore, will not require further development or qualification. Additional methods for payload bay stowage would consider the way the payload is arranged, pallet configuration, etc.

4.3.5 Construction Aids

Additional TV and lighting (over and above that presently planned) is certain to be required for space construction. The fixture locations providing maximum RMS effectiveness are not within the RMS operator's FOV or the present orbiter TV viewing (see Figure 4.3-3). However, installation of the construction fixture as far forward as practical will provide more unobstructed volume for orbiter payload packaging on those missions on which the construction fixture is included. It is anticipated that the cost of an additional TV installation or modification of the standard forward bulkhead TV mounting will be modest in relation to the benefits to be gained from the packaging improvement.

It also is recommended that a TV unit be incorporated on the assembly fixture (see Appendix D, p. D-2) to view the operations of mating the structure or the spacecraft with the fixture. This unit would be utilized when connecting deployable structures or Segment B/C rail fixtures to the assembly fixture. A viewing target is required on the payload to aid in mating with the interface adapter.

4.4 TEST FIXTURE CONCEPT

Concept drawings for a test fixture are not included in this study; however, for the purpose of providing a ROM estimate for fixture fabrication, the following fixture characteristics were established.

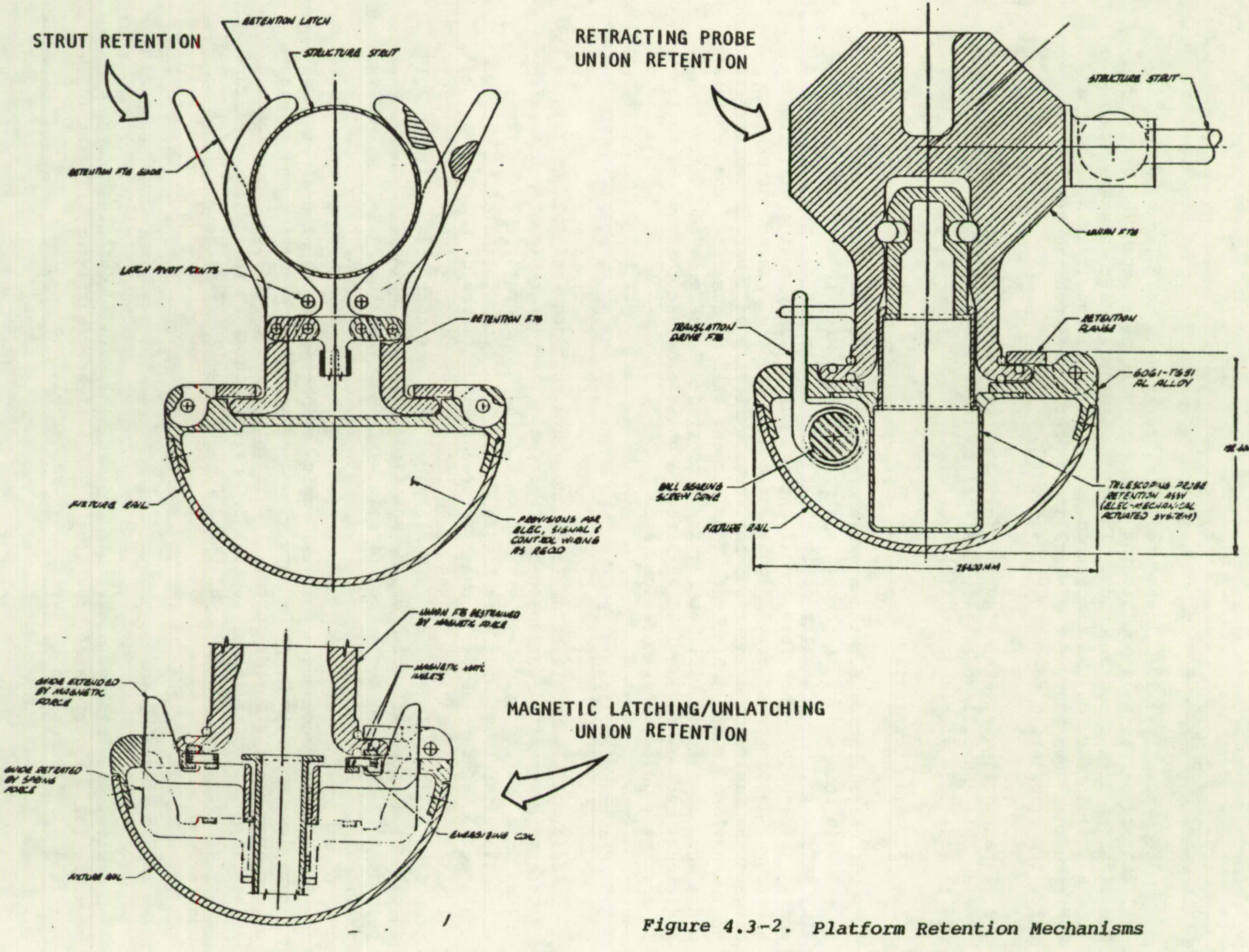


Figure 4.3-2. Platform Retention Mechanisms

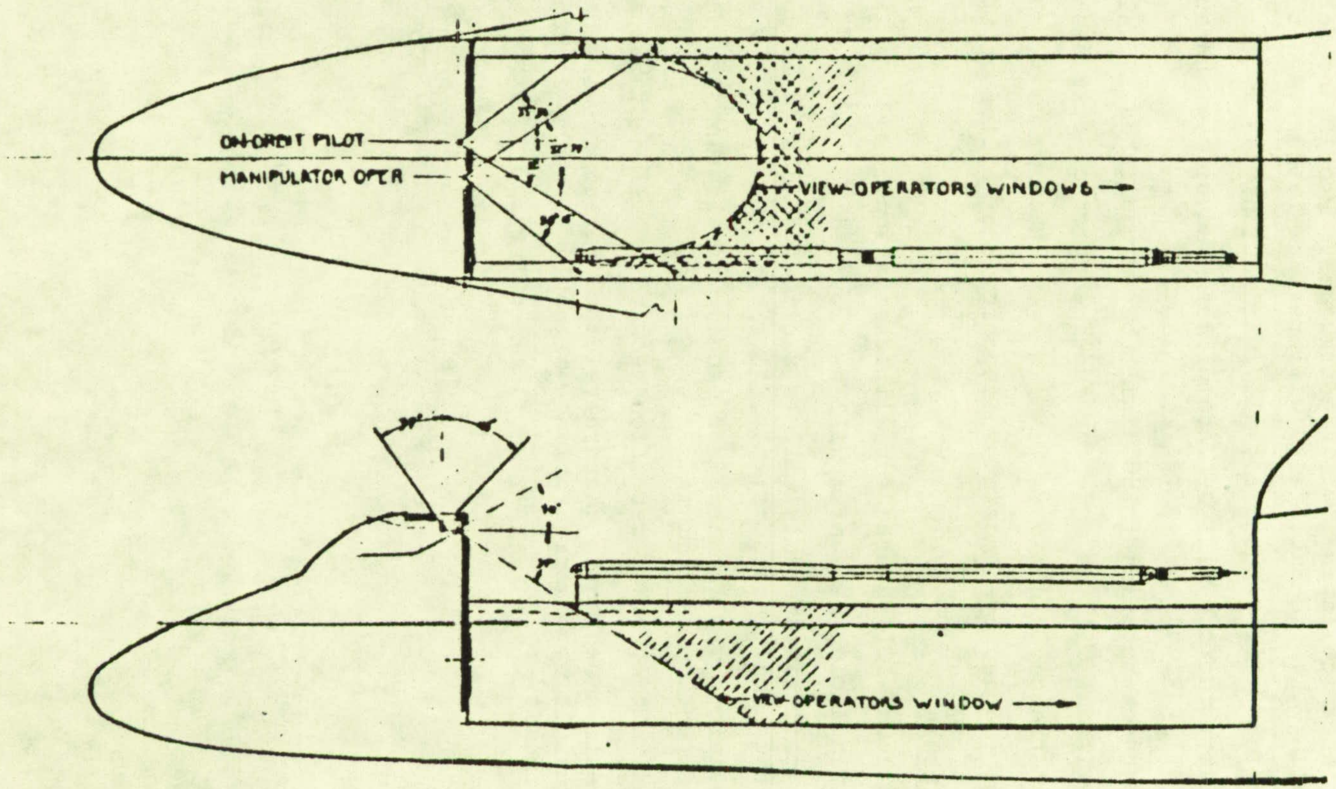


Figure 4.3-3. Field of View from Operator's Window

1. Base Fixture

   a. No provisions will be made for electrical power transfer through the interface. Pigtail connectors from base to rails will be supplied for electrical power transfer.

   b. No interface latches will be provided. Provisions for bolting the two interfaces will replace latches.

   c. Aluminum will be used for all fabrication.

   d. Joint rotations will be accomplished manually with manual stops provided as desired.

   e. Interface rotation (±180°) will be accomplished manually.

   f. Provisions will be made for added support of fixtures:

      - In the payload bay
      - In the deployed position (support from ceiling or floor)

2. Rail Fixture

   a. Aluminum will be used for all fabrication.

   b. A translating mechanism will be provided.

   c. One rail fixture only will be fabricated (design is common to both configurations).

   d. Provisions will be made for manual installation/removal of retention mechanisms.

   e. Four units of each retention mechanism will be fabricated.

   f. Retention mechanism capture/release operations will be manual in two configurations—magnetic latching/unlatching capability for one configuration will be maintained.

5.0 FIXTURE TECHNOLOGY AND DEVELOPMENT LOGIC

During an earlier task of this contract (Task 5.0), a technology development logic for systems ground verification of large space system platform construction was defined.

Figure 5.0-1 illustrates the systems that comprise a large space platform and the integration of their design into an overall systems test. Previous discussion pointed out that the construction fixture system was the key to LSS construction. As such, the development and verification of construction methods, sequence of assembly, timeline definition, and requirements imposed on the Shuttle orbiter (operational, structural, etc.) are essential prior to performing in-flight construction operations.

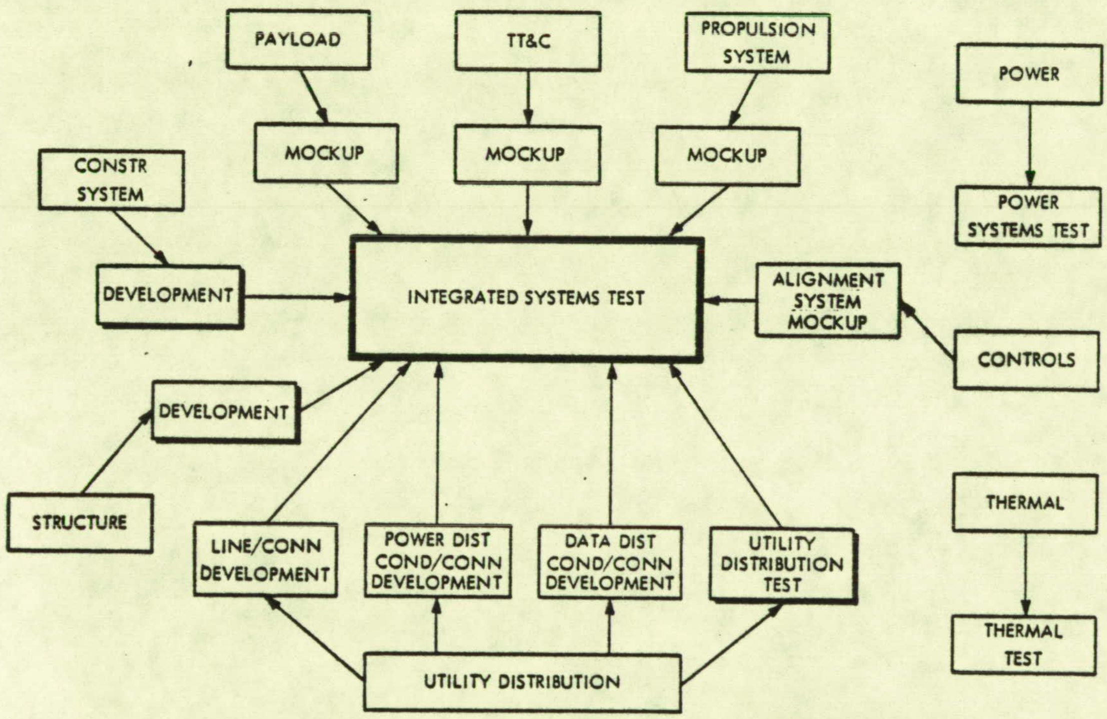


Figure 5.0-1. LSST Platform Technology Development

5.1 DEVELOPMENT LOGIC

The logic flow diagram shown in Figure 5.1-1 represents three basic phases in the development and ground verification of a construction fixture system. It begins with the definition of requirements and continues through the integrated systems testing for a total large space system.

Figure 5.1-1. Construction Fixture Technology and Development Logic

This study (including Task 7.0) has provided the initial phase of the development of the fixture. It has also provided the requirements for the fixture design, the definition of the areas needing development, a design concept for the fixture, and a ROM cost for its development.

Following this phase, a development program—designed to evaluate the areas requiring technology resolution—is planned. During this period, design and fabrication of the test fixture and component test articles will be accomplished. In addition, a test plan will be initiated defining the test requirements, test objectives, test facility requirements, and procedure for conducting the tests. Provisions will be made to support the fixture and equipment during the one-g tests. However, simulating a zero-g environment will be attempted in some areas to enhance test operations. The use of the Manipulator Development Facility (MDF) at Johnson Space Center (JSC), Houston, Texas, is presently planned, although it is understood that scheduled use must be carefully planned. The integrated fixture tests performed during this time period will provide the basis for selection of the translation and retention methods to be adopted for final fixture design, modifications that may be required to the basic fixture, recommendations for TV and lighting arrangements, and evaluation of operational sequences and timelines.

Subsequent to the integrated fixture tests, modifications to the fixture and the facility will be made (if required) in preparation for a systems integrated tests. The test plan will have, as the objective, the verification that a space platform (including systems) can be assembled on the ground using the Shuttle orbiter as the construction base and that confidence has been obtained that assembly in space is also feasible.

5.2 FIXTURE DEVELOPMENT PROGRAM COST ESTIMATE

The cost estimates for fixture development programs shown here are ROM estimates based on the fixture concept defined in Section 4.3, and assumes that the detail design effort starts with the existing layouts. These estimates also include the following conditions:

1. The test conductor, RMS operator, and test technicians will be furnished by the NASA at the MDF.

2. The MDF will be available for test usage and will include the necessary TV and lighting requirements for the tests.

For purposes of this study, the estimates include (1) Segment A fixture development (including design, fabrication, and testing) and (2) Segment B fixture development (including design, fabrication, and testing).

5.2.1 Segment A Fixture Development

This development program would be used to develop the Segment A fixture only. It would include utilizing the RMS for installing/removing a platform on the fixture, and evaluating the fixture capabilities and requirements. The design and fabrication of two small, lightweight structures simulating deployable platforms used for this purpose (probably made of wood) are included in this estimate.

The 15-month schedule, applicable to this program, is presented in Figure 5.2-1.

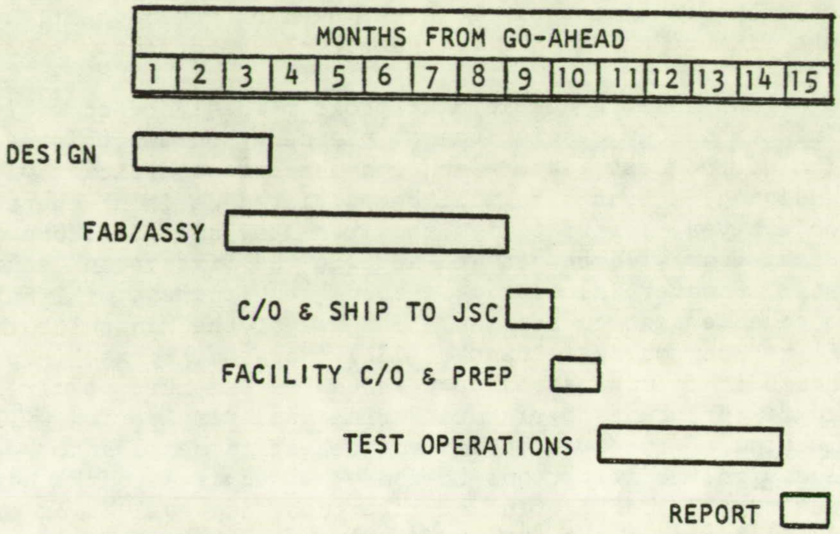


Figure 5.2-1. Segment A Fixture Development Schedule

The total cost in present-day dollars for this effort would be:

• Manufacturing (including materials)	\$ 63,000
• Engineering/Test	170,000
Total	\$233,740

5.2.2 Segment B Fixture Development

This development program would be used to develop the Segment B fixture concept. Separate tests would be performed on Segment A only, followed by the installation and testing of the translating rail system and retaining mechanisms. The 24-month completion schedule for this program is shown in Figure 5.2-2.

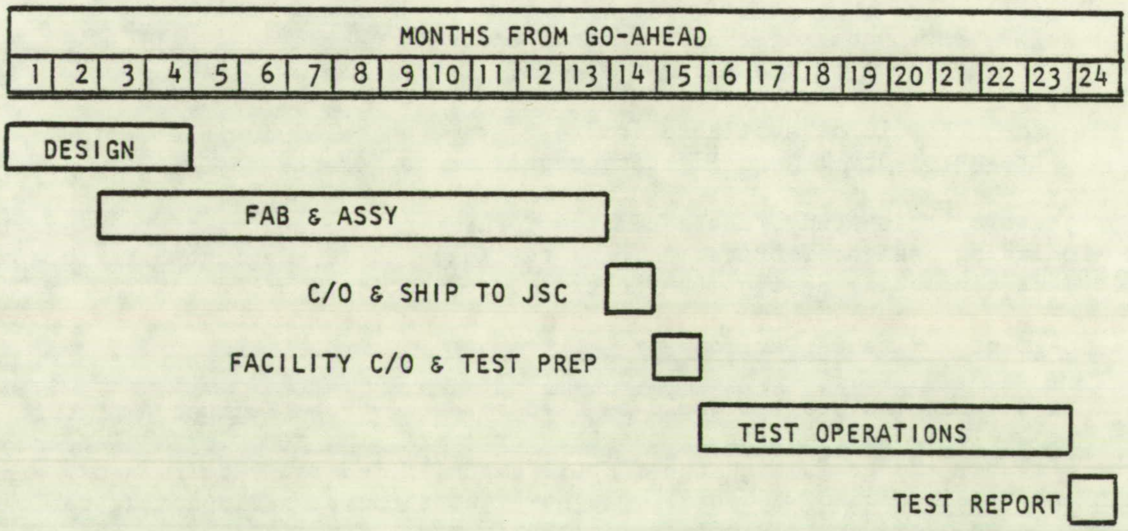


Figure 5.2-2. Segment B Fixture Development Schedule

The total cost in present-day dollars for this effort would be:

• Manufacturing (including materials)		\$260,000
• Engineering/Test		267,000
	Total	\$527,000

6.0 CONCLUSIONS AND RECOMMENDATIONS

The present study has reinforced the basic theme of the task assignment that the assembly of large space structures from the orbiter base will need to emphasize the importance of the construction fixture. The fixture requirements will vary with the size and type of platform to be utilized for the LSS space mission. Fixture requirements to provide platform translation relative to the orbiter RMS working volume became apparent as the size the platform increased.

Table 6.0-1 provides a listing summarizing general conclusions derived from the current study. Recommendations for additional study and development are summarized in Table 6.0-2.

Table 6.0-1. Construction Fixture Study Conclusions

Simple orbiter payload bay installed construction fixtures will be adequate for small deployable-type platforms.
Erectable platforms requiring the assembly of components (struts and unions) or subassemblies require more complex fixtures, such as rail-mounted, multi-point attachment units.
Design of the platform and construction fixture(s) must incorporate the requirements for installation of utility distribution systems and payloads.
Fixture requirements common to several fixture types and applications can be identified.
Scale models or full-scale mockups are required to adequately determine operational complexities of construction fixture, platform, and RMS relationships.
Construction timeline estimation will require additional ground test simulation and/or orbiter-based space experimentation for determining basic assembly operations data.
Construction fixture development can be accomplished with an incremental approach during which additional capability is achieved by the addition of "improvements" to a basic fixture.
Construction fixture attachment to the orbiter bay requires careful analysis of structural attach point availability and restrictions.
Construction fixture stowage in payload bay is an important design consideration.
TV and lighting arrangements will be an integral part of space construction planning.
The capability of the orbiter RMS to support the assembly of large space systems is highly dependent on the RMS end effector system capability to provide the LSS component assembly functions such as grasp, transport, connect, align, and other operations.

Table 6.0-2. Recommendations

Prepare full-scale mockups of construction fixtures and platforms for early candidate space platforms.
Conduct ground-based simulation of platform assembly operations using simulation laboratory facilities such as the JSC MDF and MSFC Neutral Buoyance Simulator, including RMS simulators.
Determine requirements for space experiments which will benefit LSS construction fixture development.
Maintain surveillance of future (funded) space mission programs requiring LSS, and determine impact on current construction fixture design and operations concepts. Modify fixture development programs as appropriate.
Analyze tradeoffs between automated and EVA operated devices for peripheral tasks related to platform construction fixture (e.g., flight restraints, fixture deployment from payload bay, systems checkout, etc.).
Perform analysis and laboratory simulation of RMS end effector functions required or desired for LSS construction activities.
Perform analyses to determine tradeoffs between end effector complexity and LSS structural design of joints and systems and subsystems installation.

APPENDIX A
CONSTRUCTION EQUIPMENT
LITERATURE SEARCH

INTRODUCTION

An overview of space assembly scenarios to identify functions of construction fixtures for large space systems was performed as Task 7.0, also of this contract. Its purpose was to document the studies that have been performed (government and industry) for construction in space and the construction fixtures conceived to accomplish these operations. This appendix contains a compilation of the information obtained in this literature search. A listing of the references surveyed is shown on page A-1.

Detail analyses were accomplished for five of the eight documents which appeared related to the LSS Construction Equipment subject. The other three documents did not have sufficient equipment detail to allow listing of construction fixture functions and requirements. The lists established from the five reports utilized were analyzed to construct functions and requirements for the assembly fixture recommendations of the current study.

Each of the following five reference summaries is organized in a standard format. The first sheet provides the document identification and illustrative sketches of the subject Large Space System. The next sheet(s) provide(s) a summary table indicating construction equipment type, interfaces with orbiter and platform, and functions performed. The third section contains a brief verbal description of the construction equipment requirements plus a construction equipment requirements summary table.

SUMMARY OF LITERATURE SEARCH DOCUMENTS

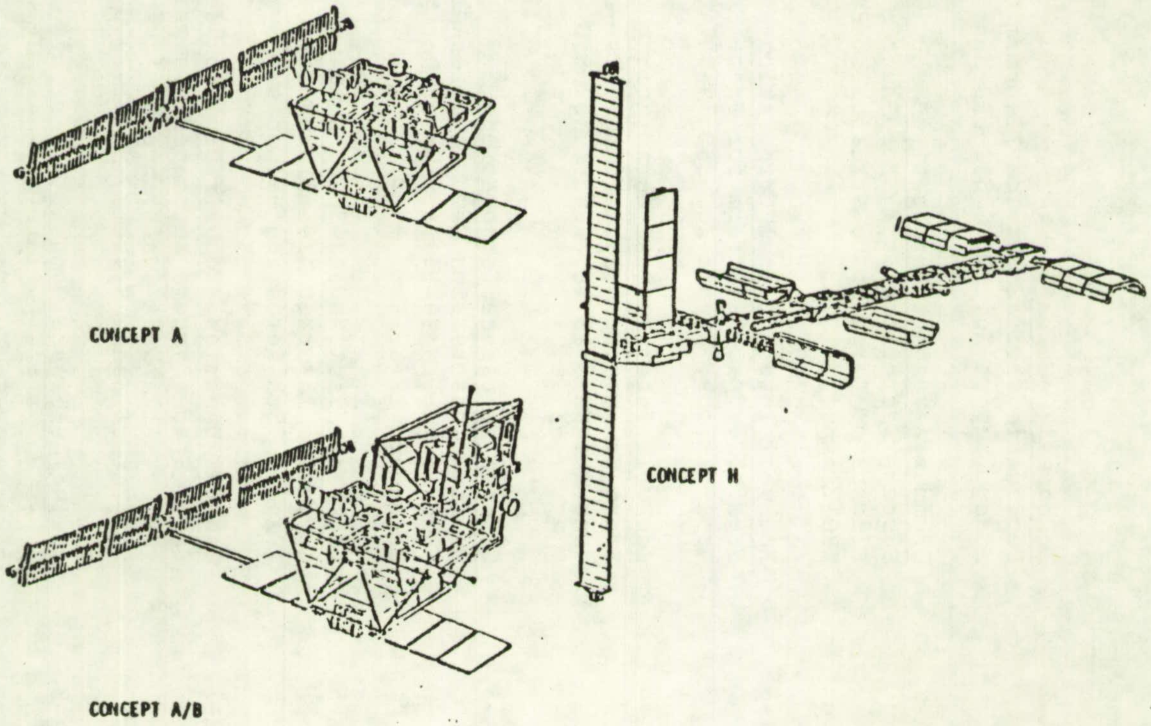
REFERENCE	
A-1	McDonnell Douglas* *Deployable Orbital Service Platform Conceptual Systems Study*, Report No. MDC G7832-DRD-MA664TAP, March, 1979.
A-2	Grumman Aerospace Corporation* *Systems Definition Study for Shuttle Demonstration Flights of Large Space Structures*, Report No. NSS-LS-RP012, April, 1978.
A-3	Rockwell International Corporation* *Erectable Space Platform for Space Sciences and Applications*, Report No. SSD 79-0074, March, 1979.
A-4	Rockwell International Corporation* *Space Construction System Analysis—Data Base*, Contract NAS9-15718, Report No. SSD 79-0125, June, 1979.
A-5	Grumman Aerospace Corporation* *Orbital Construction Demonstration Article Study*, Contract No. NAS9-14916, Report No. NSS-)C-RP008, December, 1976.
A-6	Lockheed Missiles and Space Company *Automatic In-Orbit Assembly of Large Space Structures* (Paper, 13th Aerospace Mechanisms Symposium, April 1979).
A-7	General Dynamics, Convair Division/General Electric *Large Space Systems Automated Assembly Technique* (Paper, AIAA/NASA Conference on Advanced Technology for Future Space Systems, May 1979).
A-8	Boeing Aerospace Company *Large Space Erectable Structures—Building Block Structures Study*, Contract NAS9-14914, April, 1977.

*Construction summaries provided.

DOCUMENT REVIEWED: DEPLOYABLE ORBITAL SERVICE PLATFORM CONCEPTUAL SYSTEMS STUDY
DATE OF STUDY REPORT: MARCH 1979
BY: MCDONNELL DOUGLAS ASTRONAUTICS COMPANY
REPORT NO: MDC G7832/DRD-MA664TAP

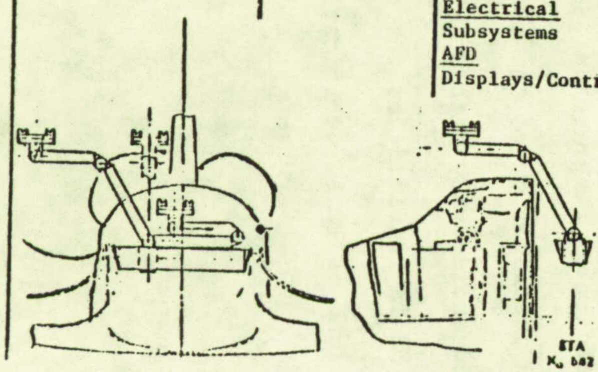
REF. A-1

DEPLOYABLE STRUCTURE CONCEPTS FOR SCIENCE/APPLICATIONS PAYLOAD PLATFORM



LSS PLATFORM DEPLOYABLE CONSTRUCTION TRAPEZOIDAL CONFIGURATION (4.5x10.9 EACH PLATFORM)

TYPE OF CONSTRUCTION EQUIPMENT USED	LOCATION IN ORBITER	INTERFACES		FUNCTIONS PERFORMED	AXIS OF OPERATION	DEGREE OF OPERATIONAL ROTATION REQUIRED
		WITH ORBITER	WITH PLATFORM			
Remote Manipulator System (RMS)	X_o 679.5 Left Hand Longeron	Mechanical Longeron Shoulder Attach Retention Latch System Software GPC Electrical Subsystems AFD Displays/Controls	Mechanical/ Structural End Effector to Platform Grapple Fixture	1- Remove Platform From P/L Bay in Folded Position and Place on Berthing Adapter 2- Remove Pallets From P/L Bay and Install on Platform 3- Capture Free-Flyer 4- Berth Prop. Stage to Adapter 5- Berth Platform to Prop. Stage	All Axes	Within RMS Capability
Berthing Adapter	Rotating Base Pivot X_o 582 Y_o = 47.2 Z_o = ?	Struct/Mech Base Ftg Bridges P/L Bay - Longeron Attach Software GPC Electrical Subsystems AFD Displays/Controls	Docking Interface - Electrical Umbilical - Latching Mechanisms for Struct Tie Between P/L and Adapter	1- Contain Platform Structure During Deployment 2- Contain Platform During Pallet and Systems Install 3- Rotate Platform to Enable Full RMS Capabilities	Y-Axis	Berthing Port Tilt - 45° Outboard 20° Inb'd Rotate - ±180° Arm Base Pivot Rotate - 120° X-Z Y-Z Planes Middle Pivot Rotate +120° -0°



REF. A-1

DEPLOYABLE ORBITAL SERVICE PLATFORM
CONCEPTUAL SYSTEMS STUDY
SUMMARY OF CONSTRUCTION EQUIPMENT
REQUIREMENTS

REF. A-1

The construction method defined in this study is a deployment type. The platform structure is carried to orbit pre-assembled, but in a folded configuration. The RMS removes the platform from the payload bay in the folded configuration and installs it on the orbital berthing adapter (OBA). Once the RMS has affected a berthing condition with the berthing adapter the structure is released from its containment and deployed into the desired configuration. This is accomplished using a spring snubber mechanism. The only two pieces of construction equipment discussed in the study were the OBA and the remote manipulator system (RMS). The function of the OBA is strictly to restrain and position the platform assembly during deployment and installation of the pallets and other systems by the RMS. The RMS was used exclusively without EVA operations by the crew. It is estimated that 68 MH is required for the deployment of two platforms, installation of four payload pallets, verification of platforms and release from the orbiter.

CONSTRUCTION REQUIREMENTS SUMMARY

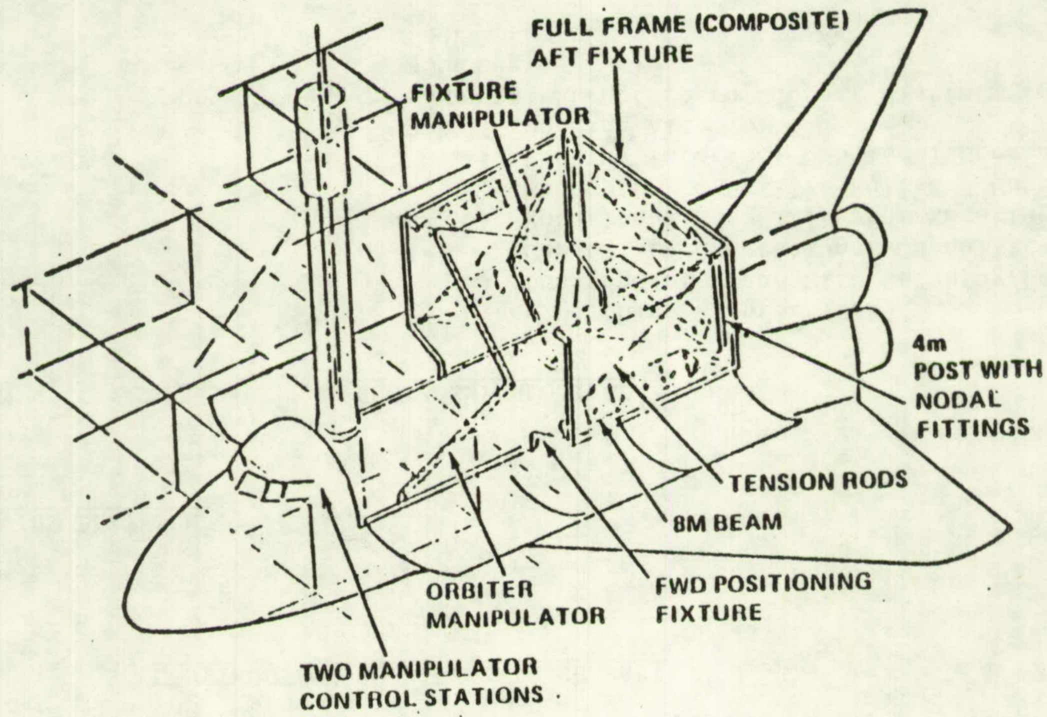
REF. A-1

DEPLOYABLE ORBITAL SERVICE PLATFORM
CONCEPTUAL SYSTEMS STUDY

DEPLOYABLE CONSTRUCTION	EQUIPMENT REQUIRED
	1- Orbiter Berthing Adapter (OBA) a) Docking Interface With Latching/Unlatching Capability & Rotational Capability b) Rotational Capability for Rotating Entire Mechanism to Utilize Full RMS Capabilities c) Docking Interface Umbilical Mechanism d) Docking Aids 2- Special Structure to Support Platform for Orbiter Packaging 3- RMS

DOCUMENT REVIEWED: ORBITAL CONSTRUCTION DEMONSTRATION ARTICLE STUDY
DATE OF STUDY REPORT: DECEMBER 1976
BY: GRUMMAN AEROSPACE CORPORATION
REPORT NO: NSS-OC-RP008

REF. A-2



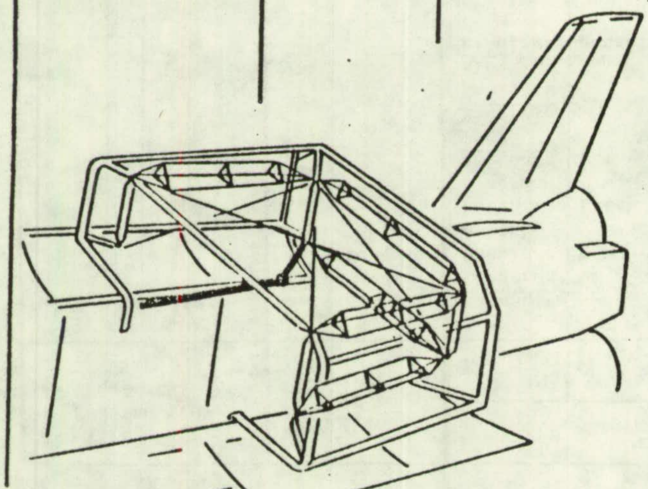
CONSTRUCTION WORK PLATFORM, HYBRID CONSTRUCTION—DEPLOYABLE/ERECTABLE BEAM ASSEMBLY—CUBE MODULE CONFIGURATION—32 m x 72 m

TYPE OF CONSTRUCTION EQUIPMENT USED	LOCATION IN ORBITER	INTERFACES		FUNCTIONS PERFORMED	AXIS OF OPERATION	DEGREE OF OPERATIONAL ROTATION REQUIRED
		WITH ORBITER	WITH PLATFORM			
RMS on Orbiter	X_o 679.5 Left Hand Longeron	Mechanical Longeron Shoulder Attach Retention Latch System Software GPC Electrical Subsystems AFD Displays/Controls	Mechanical Grapple Fixture	1- Removes Deployable Beam From Payload Bay and Translates to Fixture 2- Joins Beams in Fixture to Make Cube Module 3- Translates Cube Module to Platform for Attachment to Traveler 4- Using Special End Effector Provides Hard Dock Capability for Probe and Tension Rod Tightening 5- Remove Core Module From Payload Bay and Install on Docking Port	All	Within Capability
RMS on Platform	N/A	Electrical Docking Port Connection Electrical Subsystems AFD Displays/Controls	Mechanical Attaches to Platform Carriage	1- Attaches Cube Module to Platform 2- Installs System/Payloads to Platform	All	Within Capability

REF. A-2

CONSTRUCTION WORK PLATFORM, HYBRID CONSTRUCTION—DEPLOYABLE/ERECTABLE BEAM ASSEMBLY—CUBE MODULE (CONT.)

TYPE OF CONSTRUCTION EQUIPMENT USED	LOCATION IN ORBITER	INTERFACES		FUNCTIONS PERFORMED	AXIS OF OPERATION	DEGREE OF OPERATIONAL ROTATION REQUIRED
		WITH ORBITER	WITH PLATFORM			
Subassembly Fixture 1) Fwd Position-Fixture 2) Full Frame AFT Fixture	From Mid Bay to AFT Bulkhead	<u>Mechanical</u> Attach to Longeron Both Sides	Nodal Attachment During Assembly	1- Locates 4 Nodal Fittings Positions and Locks Posts and Nodal Fittings in Place for Beam Assembly	None	None



REF. A-2

REF. A-2

SUMMARY OF STUDY

The OCDA consists of four major elements: core module, platform, rotatable boom, and solar array. The core module, rotatable boom, and solar array are deployable from the orbiter bay. The platform is constructed in a hybrid method in that deployable tri-beam subassemblies are joined to form cell (bay) assemblies which are subsequently joined to form the platform. In order to accomplish the cell build-up, an assembly fixture is utilized which is attached to the orbiter payload bay longeron attach points. The fixture locates four nodal fittings used to assemble the corner posts and tri-beams. Two RMS's are also utilized—one orbiter based, the other located on the rotating beam traveler. The RMS incorporates a special end effector used to operate a tension rod device and the device to "hard mate" the tri-beam probe fittings at the nodes.

Four approaches were assessed for construction of the OCDA:

1. *Manned Assembly*—Construction is accomplished entirely by crew EVA using MMU, etc.
2. *Man Assisted by Machine*—Installation of deployed beams in fixture and attachment of the cell assembly to existing platform structure is accomplished by crewmen with the use of manipulators to transport the subassemblies.
3. *Machine Assisted by Man*—This concept uses the manipulators to the greatest extent possible. Deployment of the beams and installation into the fixture is accomplished by manipulators. Manipulators transport subassemblies to the assembly site where platform manipulators position and complete attachment. Crewmen only monitor and check final alignment.
4. *Major Assembly by Machine*—Complete automated in-space fabrication and assembly. This relies on a number of fabrication plants producing structure in parallel.

Completion of the OCDA required three orbiter flights—each flight carried the assembly fixture.

The reduction in assembly time using the "Machine Assisted by Man" approach was offset by the length of time construction could be carried out. EVA was limited to approximately six-hour shifts twice a day, or twelve hours construction time per day.

CONSTRUCTION REQUIREMENTS SUMMARY

REF. A-2

ORBITAL CONSTRUCTION DEMONSTRATION ARTICLE STUDY

HYBRID CONSTRUCTION - DEPLOYABLE/ERECTABLE

EQUIPMENT REQUIRED

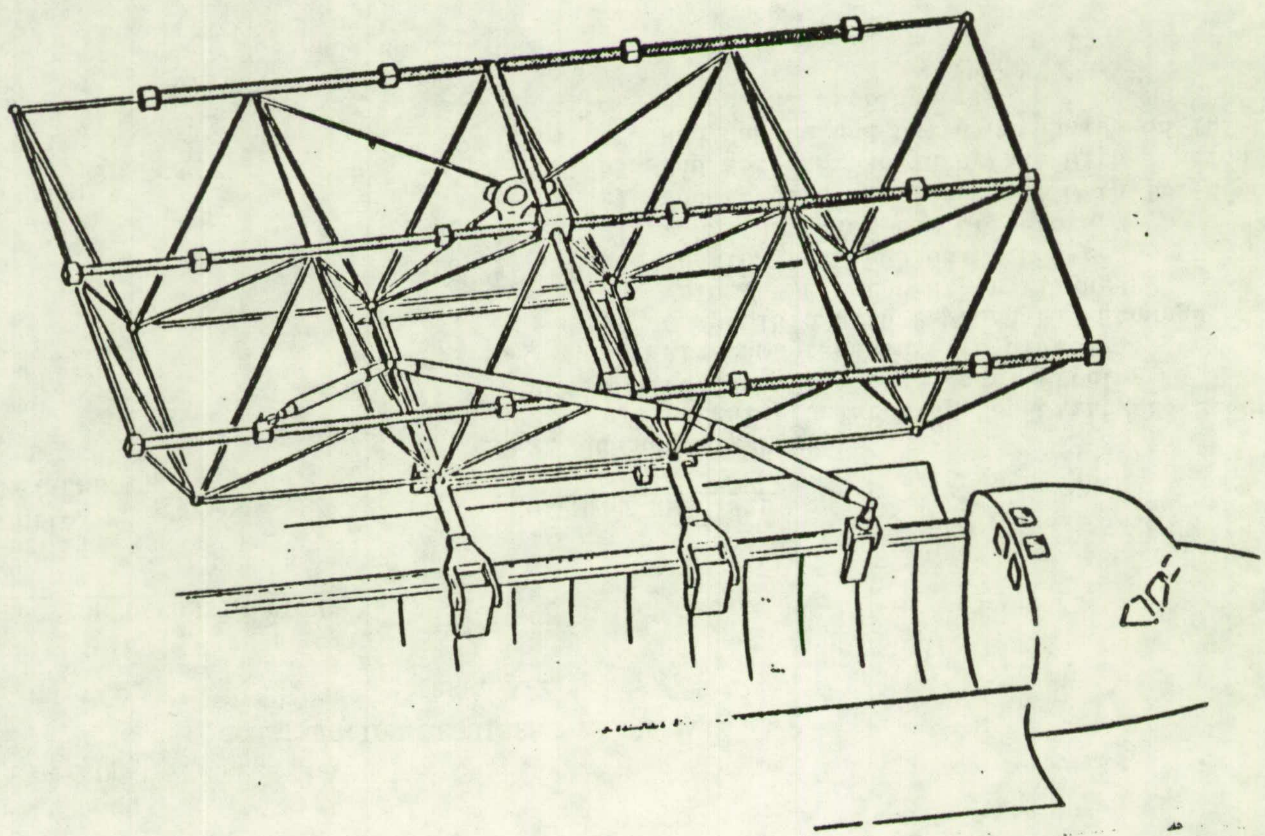
1- Subassembly Fixture
   - a) Latching/Unlatching Capability to Secure/Release Posts and Nodal Fittings
   - b) Attachment Feature to Orbiter
   - c) Compatible with Payload Bay Stowage Volume - First Orbiter Flight

2- Cable/Tension Rod Tensioning Device

3- Orbiter RMS With Two End Effectors
   - a) End Effector to Interface With Tri-Beam
   - b) End Effector to Interface With Tension Rod/Cables and Drive Mechanism on Tri-Pod Probe End Fitting

DOCUMENT REVIEWED: ERECTABLE SPACE PLATFORM FOR SPACE SCIENCES AND APPLICATIONS
DATE OF STUDY: MARCH 1979
BY: ROCKWELL INTERNATIONAL, SATELLITE SYSTEMS DIVISION
REPORT NUMBER: SSD 79-0074

REF. A-3



ERECTABLE AREA PLATFORM CONSTRUCTION, PENTAHEDRAL CELL, BALL-END-STRUT/SOCKET-UNION KITS, 9.1 x 18.3 m PLATFORM

TYPE OF CONSTRUCTION EQUIPMENT USED	LOCATION IN ORBITER	INTERFACES		FUNCTIONS PERFORMED	AXIS OF OPERATION	DEGREE OF OPERATIONAL ROTATION REQUIRED
		WITH ORBITER	WITH PLATFORM			
Platform Assembly Fixture (AF)	Attach to Left Hand Longeron, at Stations 942 & 1158	<u>Mechanical</u> Longeron & P/L Bay Structure <u>Electrical</u> Subsystems <u>AFD</u> Displays/Controls	Platform Unions	1. Grip/Release Platform Unions in Assembly Location 2. Translate Assembled Platform Cell(s) Fore and Aft as Required 3. Translate Partially Assembled Platform Outboard for Next Assembly Sequence 4. Restrain Platform During Systems/Payload Installation	X,Y-Axes	None
Remote Manipulator System (RMS)	Xo = 679.5 Left Hand Longeron	<u>Mechanical</u> Longeron Shoulder Attach Retention Latch System <u>Software</u> GPC <u>Electrical</u> Subsystems <u>AFD</u> Displays/Controls	End Effector Grapple Points	1. Assists Deployment of AF to Operating Position 2. Transfers Platform Components From Storage to Assembly Location 3. Performs Component Installation on AF and/or Structure	Y,Z-Axes	Within Capability

REF. A-3

ERECTABLE AREA PLATFORM CONSTRUCTION, PENTAHEDRAL CELL, BALL-END-STRUT/SOCKET-UNION KITS (CONT.)

TYPE OF CONSTRUCTION EQUIPMENT USED	LOCATION IN ORBITER	INTERFACES		FUNCTIONS PERFORMED	AXIS OF OPERATION	DEGREE OF OPERATIONAL ROTATION REQUIRED
		WITH ORBITER	WITH PLATFORM			
RMS' (Cont'd)				(Cont'd)		
				4. Performs Platform Subsystem and Payload Installation on Platform	TBD	TBD
				5. Remove Complete Platform Assembly From PAF, Rotate 180° reinstall in AF (to Assist in Utility Duct Installation)	Z Axis	180°
				6. Translate Platform Assembly From AF to Power Module, Dock With Power Module	X,Y,Z	Up to 180°
				7. Assist in Return of AF to Orbiter Bay, Prepare for Orbiter Return Flight	Y,Z	180°

SUMMARY OF STUDY
REF. A-3

The construction method concept proposed for this study was designated as an "erectable" system. In this concept prefabricated platform components are brought to the satellite assembly orbit by the Shuttle Orbiter, and sequentially attached to previous structural components with the aid of a platform assembly fixture (AF) and the orbiter remote manipulator system (RMS). The Space Sciences and Applications platform support services are to be supplied by a power module (e.g., 25 kW).

The activation of the power module, the construction of the platform, the attachment of the platform to the power module, the checkout of the power module/platform combination, and the separation of the satellite into a stable orbit will all be accomplished on the first orbiter flight. The science and applications payloads will be installed during orbiter revisits to the platform. The general platform construction sequence is summarized as shown in Figure 1.

The approximate assembly time from activating the assembly fixture through completion of subsystems checkout was estimated to be 12 hours. EVA assist was used only during the installation of the utility ducts and to dock the platform to the utility module. Additional EVA assist would probably have resulted in reduction of assembly time.

PLATFORM CONSTRUCTION SEQUENCE

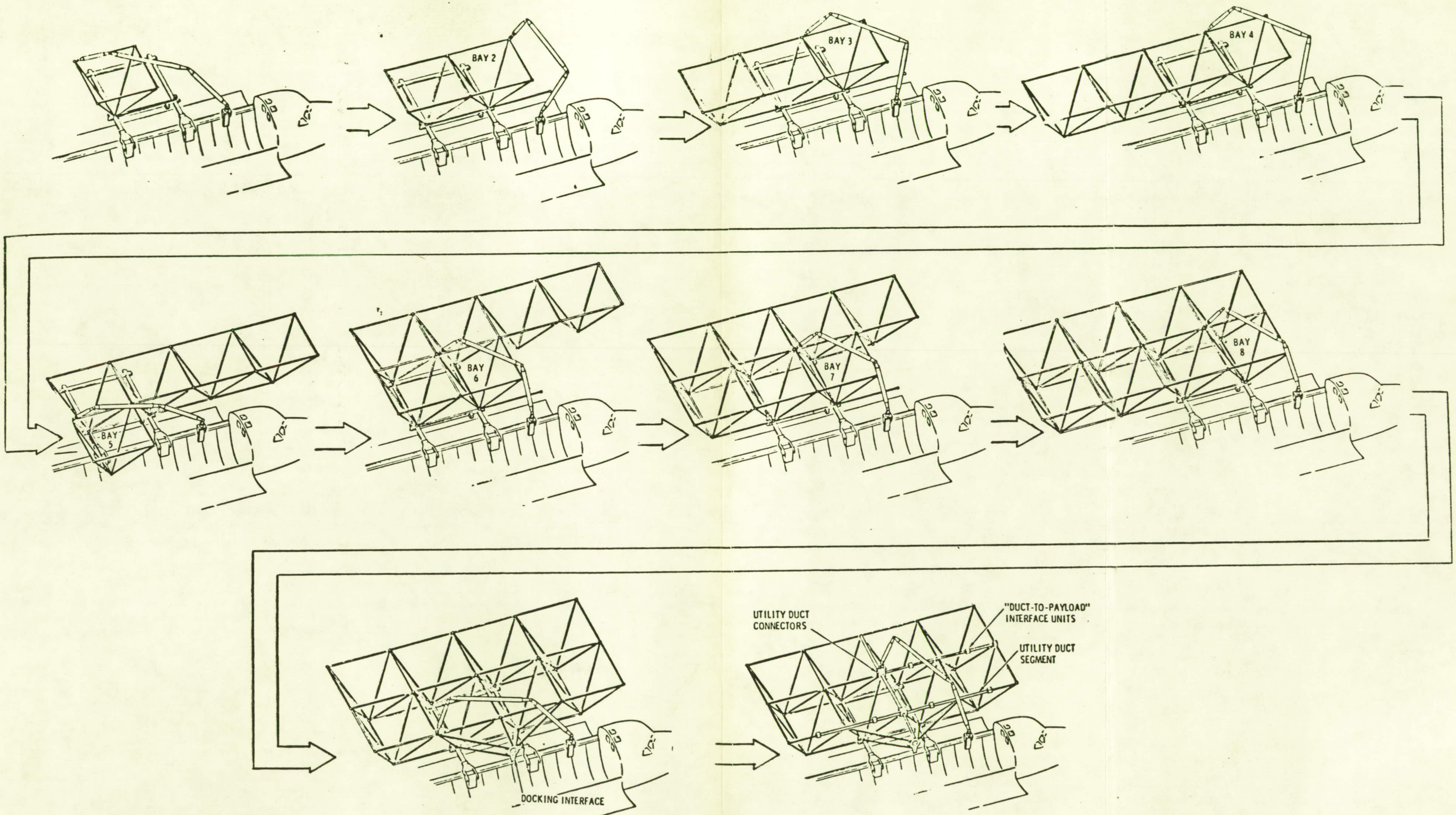


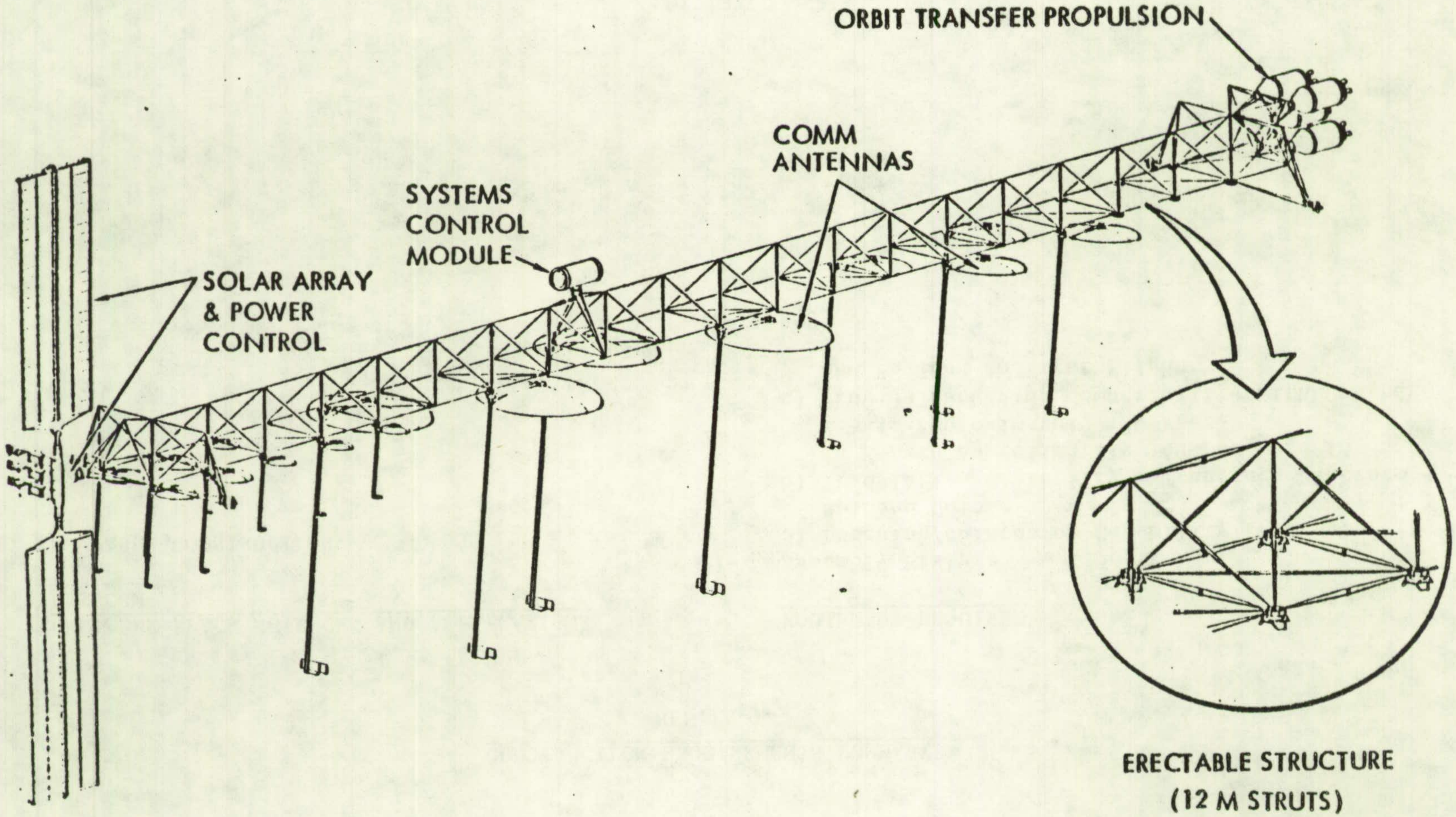
Figure 1

CONSTRUCTION REQUIREMENTS SUMMARY

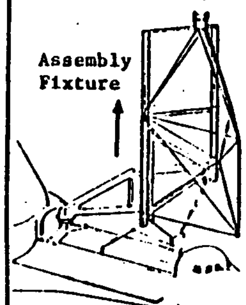
REF. A-3

ERECTABLE SPACE SCIENCES AND APPLICATIONS PLATFORM	EQUIPMENT REQUIRED
ERECTABLE CONSTRUCTION	1- Assembly Fixture a) Latching/Unlatching Capability to Secure/ Release Unions b) Translation Capability - Translate Platform in X-Axis Approximately ± 40 Feet and in Z-Axis Approximately ± 20 Feet c) Provide Packaging Compatibility With Orbiter and Payload in First Flight
	2- RMS

DOCUMENT REVIEWED: SPACE CONSTRUCTION SYSTEM ANALYSIS - DATA BASE STUDY
DATE OF STUDY REPORT: JUNE 1979
BY: ROCKWELL INTERNATIONAL, SATELLITE SYSTEMS DIVISION
REPORT NO: SSD 79-0125
REF. A-4



ERECTABLE ADVANCED COMMUNICATIONS PLATFORM—240-m PLATFORM, 12-m TRI-BEAM PENTAHEDRAL CONSTRUCTION

TYPE OF CONSTRUCTION EQUIPMENT USED	LOCATION IN ORBITER	INTERFACES		FUNCTIONS PERFORMED	AXIS OF OPERATION	DEGREE OF OPERATIONAL ROTATION REQUIRED
		WITH ORBITER	WITH PLATFORM			
Assembly Fixture 	X = Approx. 1296 On ℄ of Cargo Bay	Mechanical Longeron Attach Fittings Electrical Subsystems Pwr ≈ 4-10 kW Software GPC AFD Displays/Controls	Mounting Clamps for Platform Unions	1- Supports Platform During Construction 2- Translates Platform +Z During Erection and -Z During Module Installation 3- Special Swing Cradle Supports Thrust Structure for Assembly Prior to Attachment	Z-Axis (May be Used to Operate in Any Axis)	About Z-Axis to Effect Position Changes for Accessi-bility
RMS	X = 679.5 Left Hand Longeron	Mechanical Longeron Shoulder Attach Retention Latch System Software GPC Electrical Subsystems AFD Displays/Controls	Grapple Fixture (TBD)	1- Removes Structure Items and Equipment From Cargo Bay 2- Transports All Items to Work Station 3- Makes Structural and Attachment Installations for all Systems/Payloads	All	Within Capability

REF. A-4

2

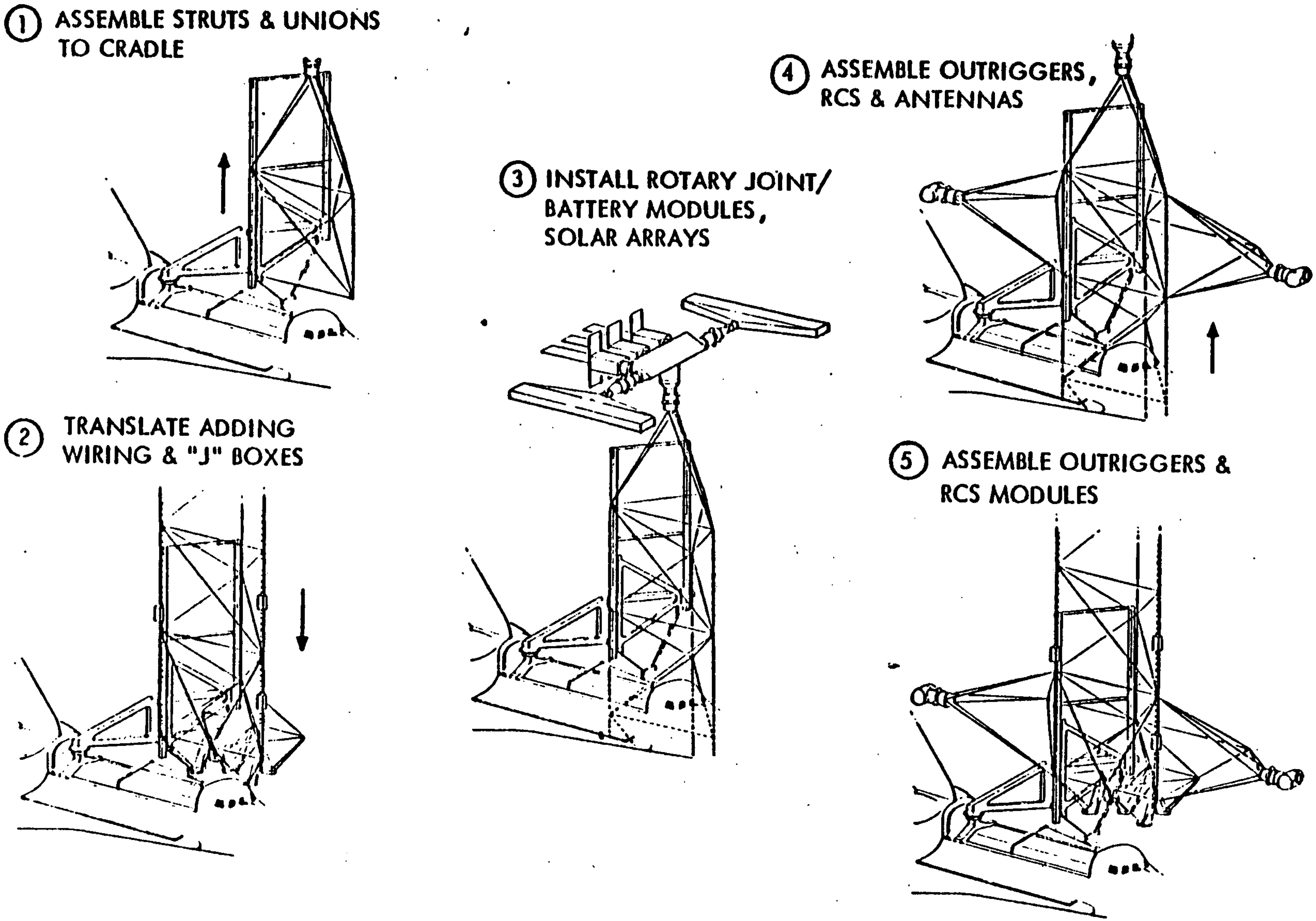
ERECTABLE ADVANCED COMMUNICATIONS PLATFORM—240-m PLATFORM, 12-m TRI-BEAM PENTAHEDRAL CONSTRUCTION (CONT.)

TYPE OF CONSTRUCTION EQUIPMENT USED	LOCATION IN ORBITER	INTERFACES		FUNCTIONS PERFORMED	AXIS OF OPERATION	DEGREE OF OPERATIONAL ROTATION REQUIRED
		WITH ORBITER	WITH PLATFORM			
Strut Assembly Fixture	X_o 930 (Approx) Right Hand Longeron	Mechanical Longeron Attach Electrical Subsystems AFD Displays/Controls	None	Restrains Struts During Unfolding and Rigidizing	Stationary Fixture	None
Cherry Picker W/Stabilizer End Effector	On RMS	Same as RMS	Grapple Fixture	1- Provides Movement for Astronaut During Assembly 2- Provides Transporting Capability for Construction Material From Payload Bay to Platform	All	Within RMS
MMU	Flight Support Station (FSS) In Payload Bay	Mechanical FSS Mounting Electrical Battery Recharge if Necessary Nitrogen QD at Orbiter 3000 psi Supply	Grapple Fixture	1- Provides Mobility for Astronaut During Assembly 2- Provides Transporting Capability for Construction Material From Payload Bay to Platform	All	All

REF. A-4

PLATFORM CONSTRUCTION SEQUENCE

REF. A-4



SUMMARY OF STUDY

REF. A-4

The Space Construction System Analysis Study encompassed more than one type of platform. For this report, however, the construction of an Erectable Advanced Communications Platform will be discussed. Basic construction of the platform is accomplished with an assembly fixture mounted in the orbiter payload bay, and a strut assembly fixture (also mounted in the orbiter payload bay) using the RMS, a cherry picker and an MMU. The data base for this study defines the critical functions to be performed and in most cases the methods/procedures to perform these functions, including alternate methods for doing.

An example of a critical function was joining struts and unions into a structural assembly. Timelines were generated for three methods. These were: (1) Using one crewman with MMU and one cherry picker operator; (2) Using RMS only operated from the AFD; and (3) Using the RMS as in Method 2 but having the struts pre-assembled in clusters. The time estimated to complete one bay (joining nine struts) for this function were 108, 180 and 137 minutes respectively for the methods named above. From this comparison it appears that construction of the platform structure may best be accomplished with pre-assembled strut clusters and an RMS if the storage in the payload bay is compatible with the volume allowance. Although EVA activity provides shorter construction timeline, total construction time is limited by the EVA operating time (approximately 6 hrs.).

During construction the assembly fixture is designed to translate in the Z-axis, however, it could be designed to operate in any axis.

CONSTRUCTION REQUIREMENTS SUMMARY

REF. A-4

SPACE CONSTRUCTION SYSTEM ANALYSIS
STUDY - DATA BASE

ERECTABLE CONSTRUCTION

EQUIPMENT REQUIRED

1- Assembly Fixture
   a) Translation of Platform in ± Axes of Construction
   b) Latching/Unlatching Capability to Secure/Release Unions
   c) Provide Packaging Compatibility with Orbiter and Payload in First Flight
   d) Rotation Capability of Pivot(s) for Position Change for Accessibility
2- RMS
3- Strut Assembly Fixture
   a) Latching/Unlatching Capability for Strut Nodes During Folding and Rigidizing
   b) Strut Length Variability Capability
4- Cherry Picker
5- MMU

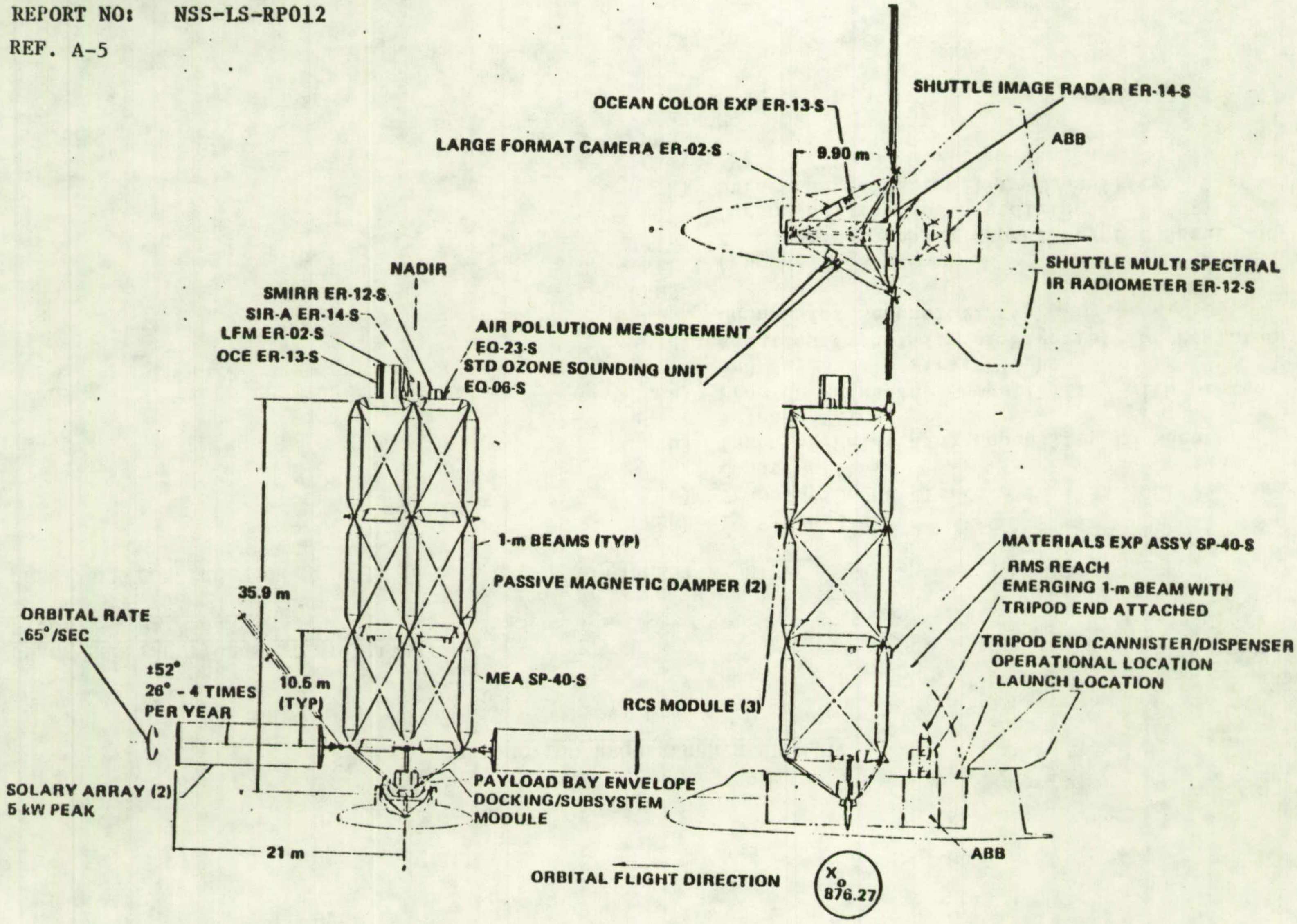
DOCUMENT REVIEWED: SYSTEMS DEFINITION STUDY FOR SHUTTLE DEMONSTRATION FLIGHTS OF LARGE SPACE STRUCTURES

DATE OF STUDY REPORT: APRIL 1978

BY: GRUMMAN AEROSPACE CORPORATION

REPORT NO: NSS-LS-RP012

REF. A-5



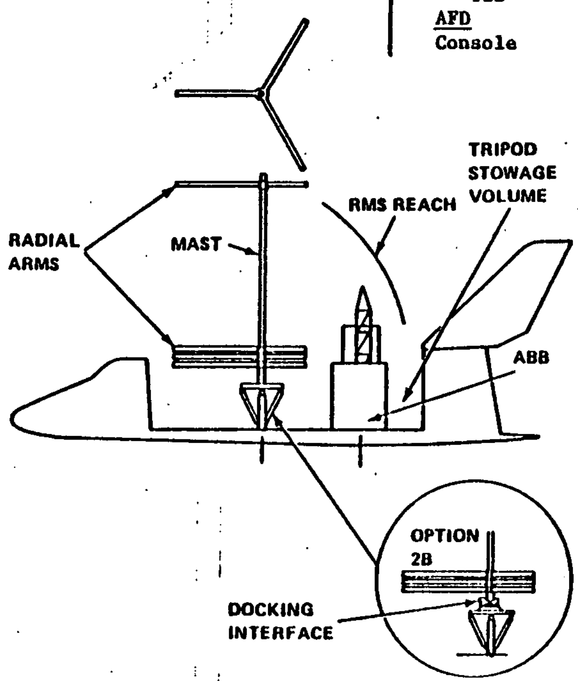
LSS PLATFORM, HYBRID CONSTRUCTION (IN-SPACE FABRICATION/ERECTABLE) TRI-BEAM CONFIGURATION (10 x 30 m)

TYPE OF CONSTRUCTION EQUIPMENT USED	LOCATION IN ORBITER	INTERFACES		FUNCTIONS PERFORMED	AXIS OF OPERATION	DEGREE OF OPERATIONAL ROTATION REQUIRED
		WITH ORBITER	WITH PLATFORM			
Automated Beam Builder (ABB) - Includes Tripod D Canister	Approx X_o = 1150 on ℄ of P/L Bay	Mechanical Keel Fittings Longeron Ftgs Electrical Subsystem Software GPC AFD Displays/Controls	None	Fabricate Triangular Beams - 10.5m Length (Node to Node) x 1m Height (Includes Tripod Ends)	Z-Axis	None
Remote Manipulator System (RMS)	X_o 679.5 Left Hand Longeron	Mechanical Longeron Shoulder Attach Retention Latch System Software GPC Electrical Subsystems AFD Displays/Controls	End Effector to Tri-Beam Grapple Fixture	1- Translate Fabricated Beam From ABB to Assembly Fixture 2- Installs Beam(s) in Fixture 3- Attach Beams at Nodal Points to Make Triangular Frame 4- Attaches Stabilizing Cables 5- Attaches Docking Berth, Sensors and Subsystems to Platform Frames	All Axes	Within Capability

REF. A-5

LSS PLATFORM, HYBRID CONSTRUCTION (IN-SPACE FABRICATION/ERECTABLE) TRI-BEAM CONFIGURATION (CONT.)

TYPE OF CONSTRUCTION EQUIPMENT USED	LOCATION IN ORBITER	INTERFACES		FUNCTIONS PERFORMED	AXIS OF OPERATION	DEGREE OF OPERATIONAL ROTATION REQUIRED
		WITH ORBITER	WITH PLATFORM			
Platform Assembly Fixture	X_o 876 on ℄ of P/L Bay	Mechanical - Keel Ftg - Longeron Ftg Electrical TBD AFD Console	Mechanical Assy Arm to Beam Attach	1- Triangular Frame Assembly Fixture Holds Beams in Place During Node Attachment and Joining 2- Translates Frame(s) Upward to Facility Assembly of Subsequent Frame(s) 3- Control Mast Contains Platform Until Total Assembly is Completed 4- Retains Fabricated Beams in Position in P/L Bay for Return to Ground	Z-Axis	



REF. A-5

SUMMARY OF STUDY

REF. A-5

The construction method defined in this study is considered a hybrid in that it combines the in-space fabrication of triangular beams and then the joining of these beams and the installation of systems in an erectable type of construction. Construction equipment discussed included the automatic beam builder (ABB), the remote manipulator system (RMS), and an assembly fixture (for this summary designated "AF"). A tripod canister was also included, but was considered to be part of the ABB. The construction operations were designed around almost exclusive use of the ABB and the RMS. It appears that the actual construction/assembly time of 100 MH est (does not include ABB qualification/verification and free flyer adaptation) could be reduced with the introduction of extensive EVA. Pre-orientation of the nodes (joints) in the fixture arms to accept the beams for installation was included in the fixture concept. This concept is good for reduction in assembly time. Also included in the assembly fixture was the tie down capability to contain the fabricated beams for earth return.

The assembly concept shown in this study is also applicable to deployable beam and ground assembled beam usage. The general platform construction sequence is shown in Figure 1.

PLATFORM CONSTRUCTION SEQUENCE

REF. A-5

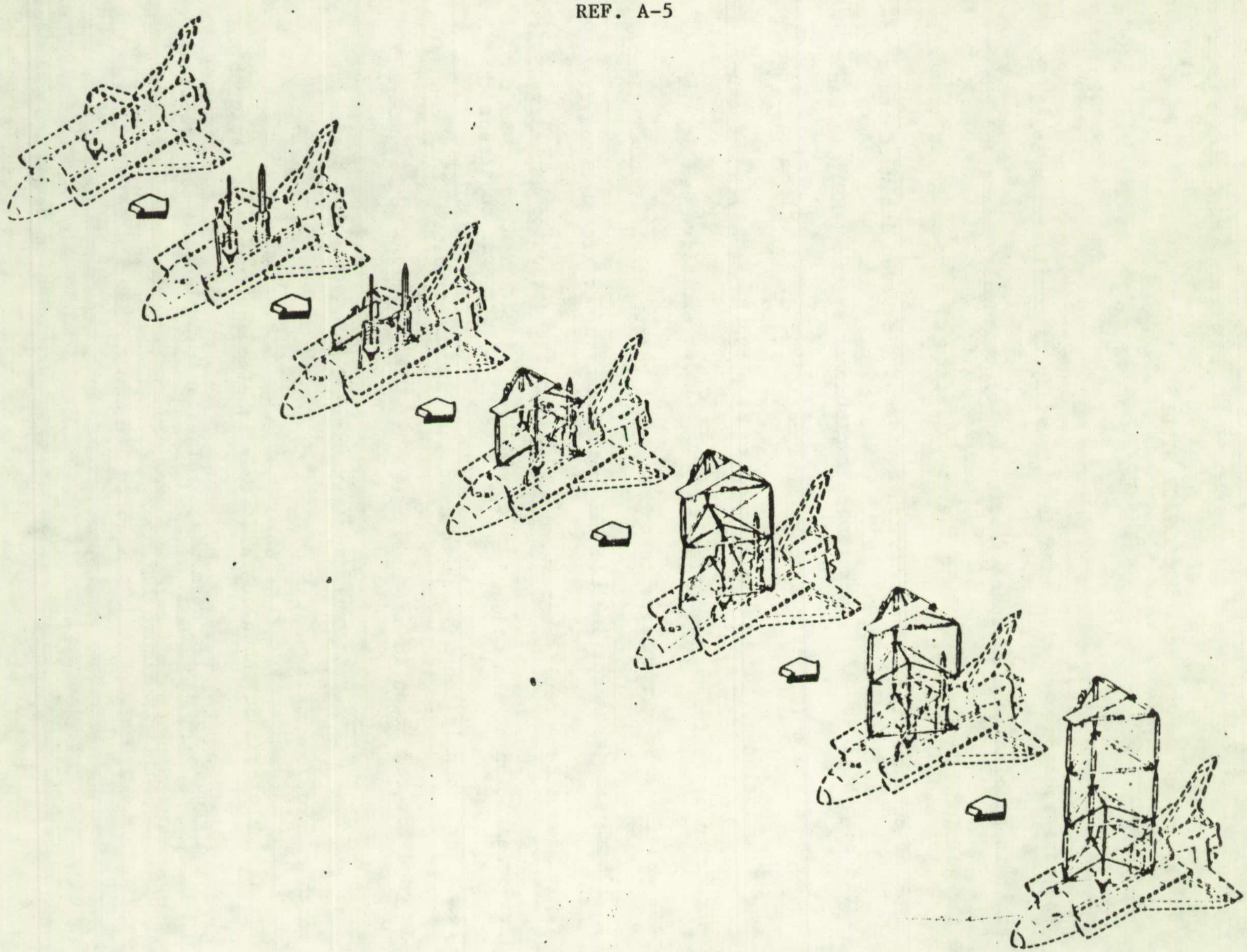


Figure 1

CONSTRUCTION REQUIREMENTS SUMMARY

REF. A-5

SYSTEMS DEFINITION STUDY	EQUIPMENT REQUIRED
Hybrid Construction In-Space Fabrication/Erect	1- Automatic Beam Builder 2- Tripod Cannister W/Welding Capability 3- Construction Fixture a) Center Mast With Latching/Unlatching Capability to Secure Horizontal Arms b) Removable Horizontal Arms W/Provisions for Node Joint Restraint and Orientation - Must be Able to Release Joint c) Attachment Feature to Orbiter - May be Docking Interface 4- Cable Tensioning Device 5- RMS With Two End Effectors a) EE to Interface With Tri-Beam b) EE to Interface With Cable/Systems Mounting

APPENDIX B

LSS PLATFORM/FIXTURE/RMS RELATIONSHIPS

APPENDIX B

LSS PLATFORM/FIXTURE/RMS RELATIONSHIPS

B.1 INTRODUCTION

The present study is to provide a review of the types of large space structures assembly fixtures that would be applicable to a variety of near-term space platforms. The "platform" function is that of providing a structure to support payload components and subsystems during the desired space mission operations. Factors to be considered include platform sizes and types, assembly (construction) fixture types, system installation techniques, and the RMS capabilities.

The general study limitations are to consider only:

- Small to medium size platforms
- Orbiter-based construction and systems installations
- Automated construction (to the extent feasible for early operations)

In the large space systems (LSS) considerations, the platform sizes will generally require some degree of erection or deployment after removal from the orbiter payload bay. The resulting assembly of platform, payloads, and supporting subsystems will thus be larger than can be packaged in the STS orbiter bay "ready to go." This will differentiate the "platform" systems from the earlier time period orbiter "delivery of payloads."

The platform assemblies considered thus will have dimensions (one or more) larger than orbiter bay dimensions of approximately 18 m in length, 4.5 m in width, and 4.5 m in height. For the very large space platforms, such as Electric Power Satellite concepts, the orbiter construction base would be inadequate for efficient construction.

As mentioned previously, orbiter-based construction will be the approach suggested for the early time period (e.g., 1985-1990) platform construction. The basic "tool" or arm considered for the platform and systems assembly activity is the standard orbiter RMS. The orbiter is designed to accept an RMS on each side of the payload bay, but the second arm would be "payload chargeable" in terms of mass and support. The second RMS also can be operated from the orbiter aft flight deck (AFD) control console, but not simultaneously with the normally provided RMS. The second RMS could be considered as a possible "construction fixture" but it is an objective of this study to determine if other simpler and/or more effective construction fixtures can be visualized for the near-term platform requirements. Further discussion of the role of the RMS, as related to the construction fixture and platform assembly, will be given in a following section.

B.2 PLATFORM TYPES

Space platform types, as related to large space systems, are divided into the three general classes of deployable, erectable, and space-fabricated. The space-fabricated platform construction involves bringing densely packaged structural beam materials to the orbital platform construction station where it is formed into the lightweight, large-volume structures desired. This construction is considered to be an advanced technique most suitable for very large structues, so will not be considered further.

Deployable and erectable platforms appear to be the major candidates for the early time-period applications. Brief scenarios for the two types are discussed below.

Deployable platform structures are completely assembled on the ground. The basic structure will contain multiple "hinges" which will allow the unit

to be folded into a package which may be contained in the orbiter bay for transport to the LSS assembly orbit. After being removed from the orbiter bay flight restraints, the deployable package is set on the construction fixture, necessary power and data interfaces to the orbiter are connected, the deployable platform restraints are released, and the platform is extended to its operational configuration. These operations are illustrated graphically in Figure B-1. Power and data lines may be integral with the deployable structure or attached later.

Erectable platform structures are assembled on orbit from a number of individual components or subassemblies. Assembly begins with the deployment of a suitable construction fixture which generally provides support for several of the unions of the platform. The initial platform components or kits are then placed on the fixture, components connected, and subassemblies restrained while successive components/kits are attached. The completed section of the platform is translated on or by the fixture to allow following areas to be assembled. Power and data line sections may be installed as construction proceeds or "laid on" at the time the payload modules are attached. The RMS functions may include release of flight restraints for the fixture and packaged components, preparation of subassemblies, and installation of the components onto the fixture or partially completed structure. Special end effectors for the RMS will be required with detail requirements dependent on the specific platform design and construction methods. A concept for erectable structure assembly is shown in Figure B-2.

B.3 FIXTURE TYPES

The analysis of construction fixtures for deployable and erectable platforms should consider a range of fixture types from the very simplest to ones which are sophisticated enough to provide a high level of assistance to the assembly procedure. The use of the complex-type fixture could, for

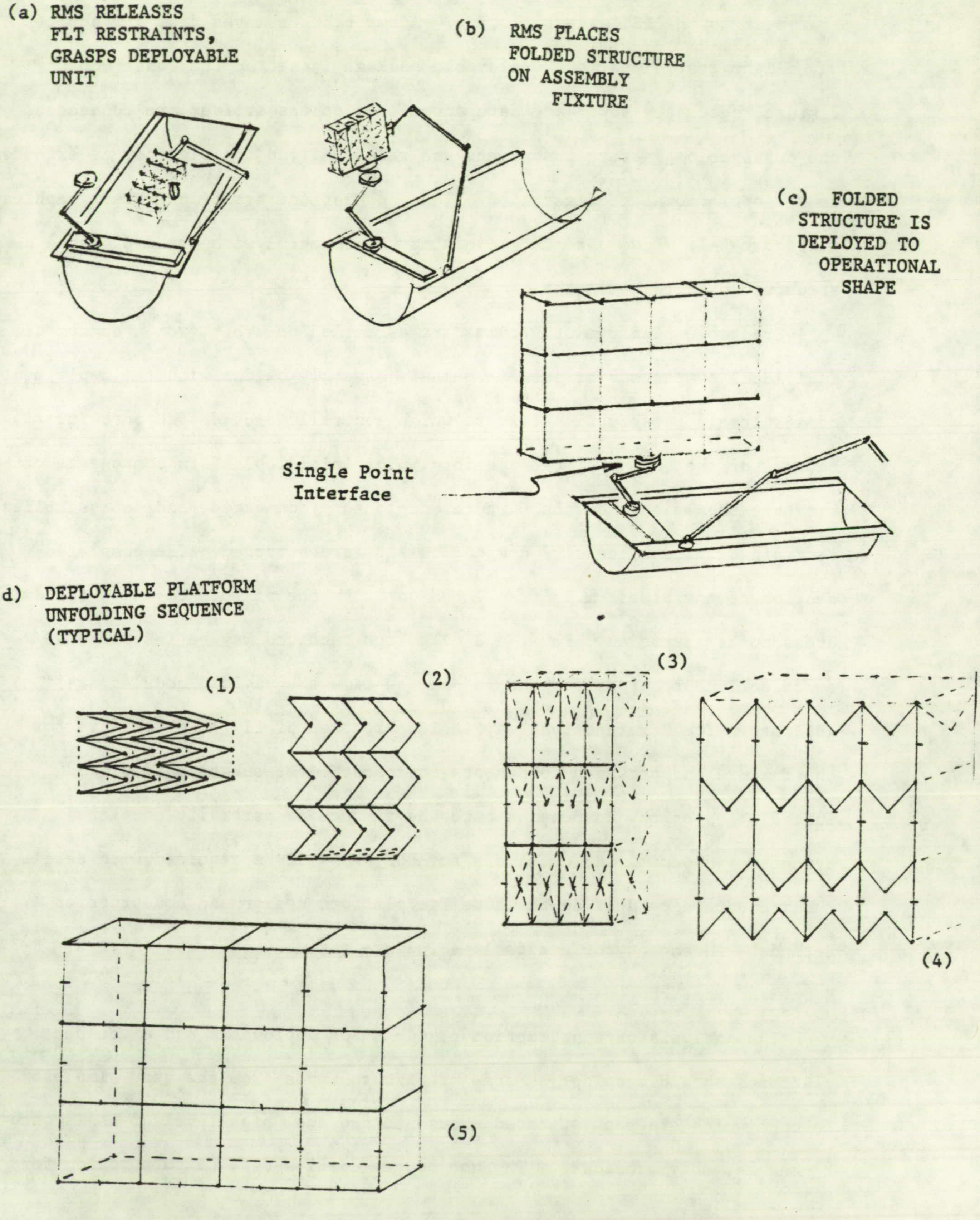


Figure B-1. Deployable Structure Preparation

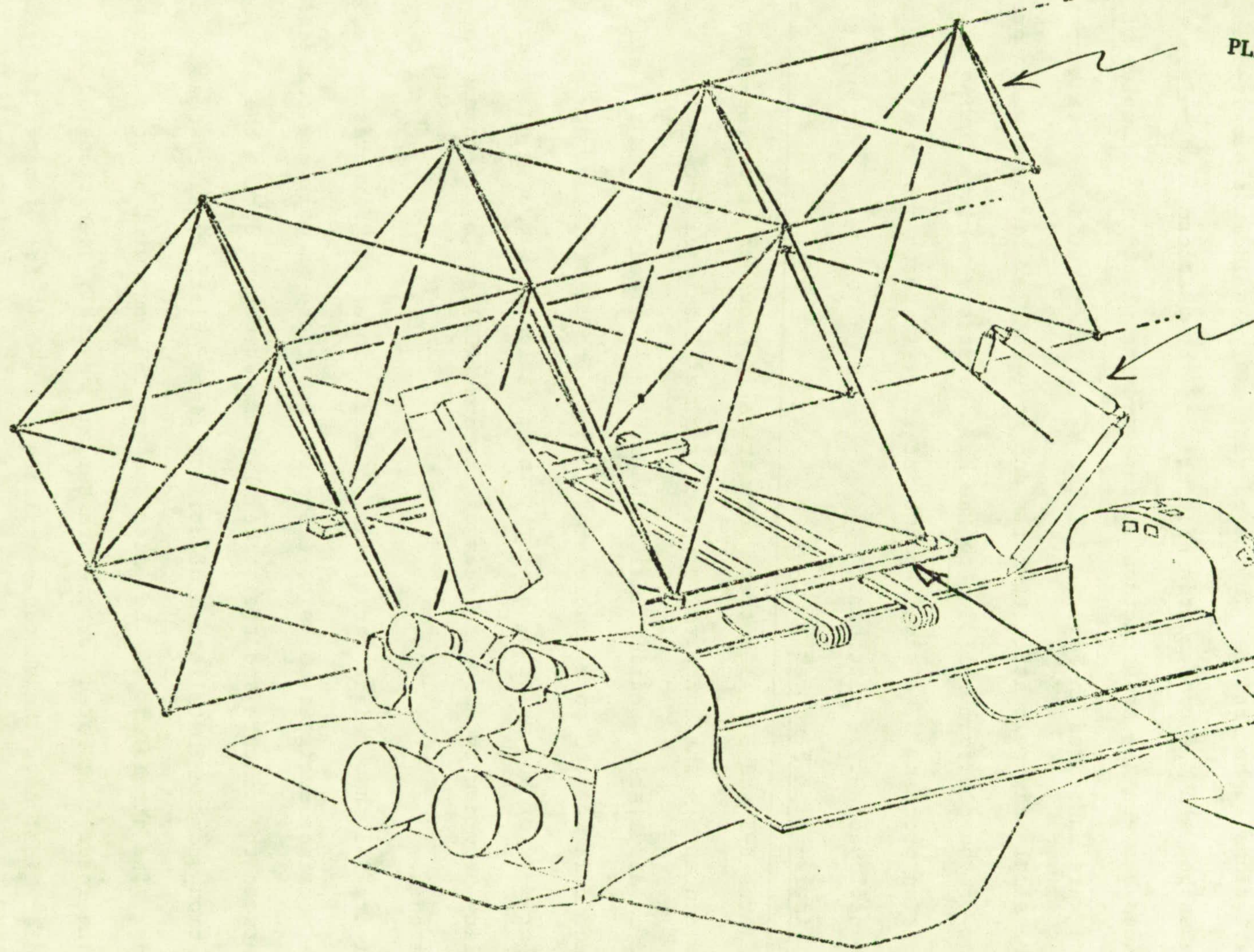


Figure B-2, · Erectable Structure Assembly

example, provide a significant reduction in the assembly time and reduce EVA requirements, compared with the provision of the simplest conceptual fixture to assemble the given platform. Fixtures which have been proposed in previous studies also should be included in the analyses.

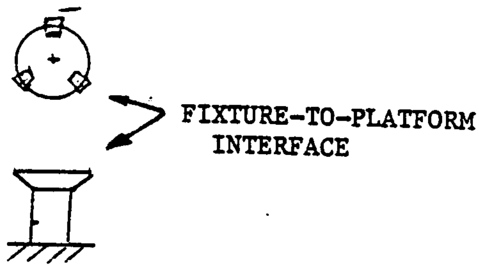
Variations to be included in the current analyses include single-point interfaces between the construction fixture and the platform, and multiple-point interfaces between the construction fixture and the platform. Examples of each of these were indicated in Figures B-1 and B-2. Other variables being considered are simple fixed-location fixtures and more complex fixtures which provide movement of the platform relative to the RMS operational volume during the construction process. The single-point interface fixtures appear most suitable for the deployable-type platforms.

B.3.1 Single-Point Fixtures

Figures B-3 and B-4 illustrate schematically a number of single-point fixture concepts. The concepts vary from a fixed interface (no moving parts) mounted in a suitable location inside the orbiter payload bay, to the single interface unit mounted on a double-arm fixture with multiple degrees of freedom at one or more of the major mechanism joint locations. Comments on added capability provided by added degrees of freedom (DOF) are noted on each of the sketches.

Figure B-3 shows eight variations of single-interface fixtures. The single-interface designation is to indicate that there is only one connecting area between the fixture and the space platform structure during the platform preparation and the installation of utility lines, platform subsystems, and payloads. The dimensions of the interface are TBD, but will be of a size to react the loads calculated for the orbiter and assembly operations of the particular missions. The sketches indicate a 1.2-m (4-ft) diameter interface of a type similar to that used on the Apollo docking operations. The Figure B-3 design variations include three concepts of a "fixed" type, where

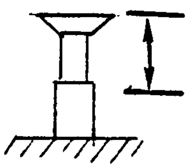
(A) SIMPLE FIXED



ORBITER

NOTE:
INTERFACE ANGLE
RELATIVE TO ORBITER
COORDINATES TBD

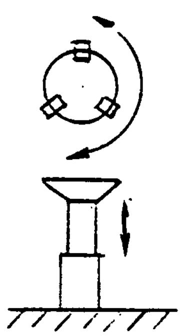
(B) TELESCOPING FIXED (1 DOF)



FIXTURE TELESCOPES UPWARD TBD DISTANCE
TO PROVIDE PLATFORM CLEARANCE ABOVE
ORBITER BAY SILL, CABIN, ETC. REMAINS
IN FIXED POSITION DURING PLATFORM PREPARATION

ORBITER

(C) TELESCOPING FIXED WITH ROTATING INTERFACE (2 DOF)

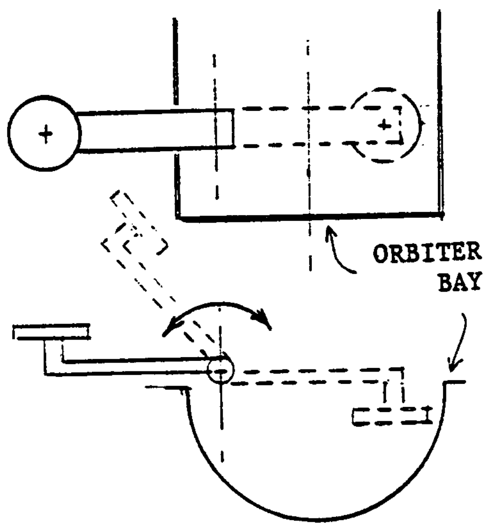


FIXTURE WITH ADDED MOBILITY OF PLATFORM
AVAILABLE BY ROTATION ABOUT AN AXIS
NORMAL TO THE INTERFACE. ROTATION POWER
TO BE PROVIDED BY FIXTURE MECHANISM ($\pm$ 180°)

(Sheet 1 of 3)

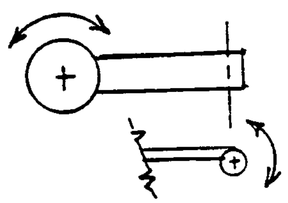
Figure B-3. Single-Point, Single-Arm Construction Fixture Variations

(D) SINGLE ARM,
ONE HINGE (1 DOF)



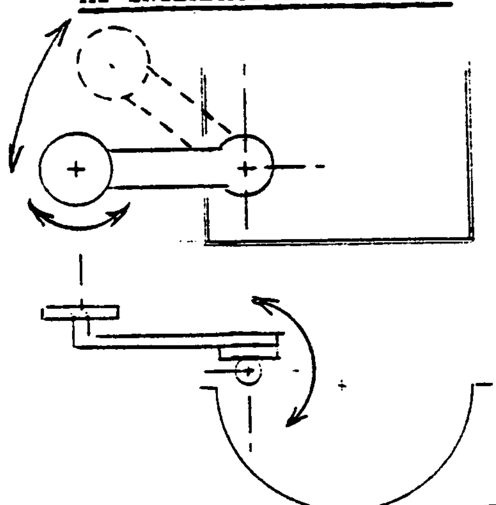
SIMPLE INTERFACE MOUNTED ON SWING-ARM. PROVIDES FOR PLATFORM PREPARATION CENTERED OUTSIDE ORBITER BAY. ALLOWS LIMITED ADJUSTMENT OF INTERFACE ANGLE RELATIVE TO ORBITER COORDINATES.
180° RANGE OF ROTATION INDICATED.

(E) SINGLE ARM, (3 DOF)
INTERFACE ROTATION



INTERFACE UNIT ROTATION SIMILAR TO ITEM (C) PROVIDES ADDED FLEXIBILITY TO ITEM D DURING PLATFORM PREPARATION

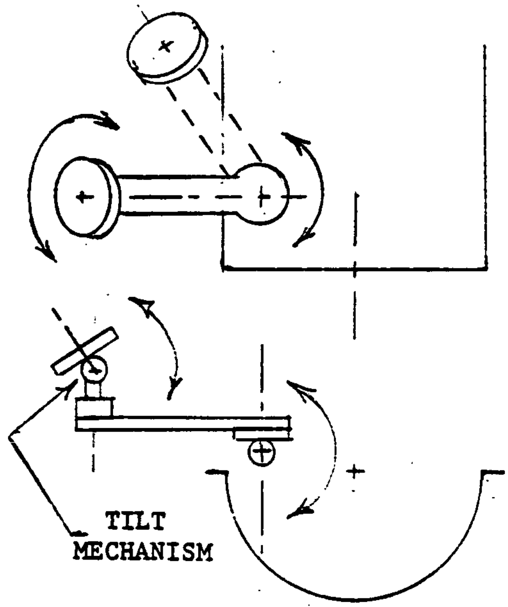
(F) SINGLE ARM, ROTATIONS AT INTERFACE & SHOULDER (3 DOF)



ADDING ROTATION AT THE "SHOULDER" JOINT OF THE SINGLE ARM FIXTURE PROVIDES MORE FLEXIBILITY OF LOCATION OF CENTER OF THE INTERFACE UNIT.
100° RANGE OF ROTATION MAY BE ADEQUATE

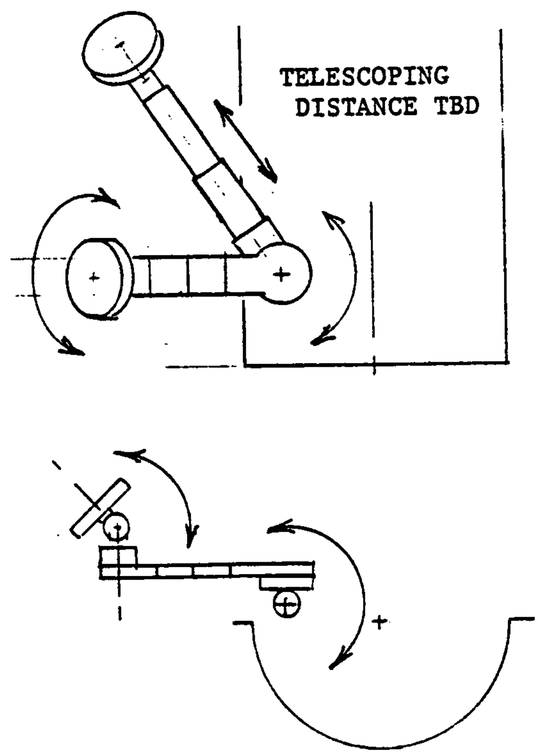
Figure B-3 (Sheet 2 of 3)

(G) SINGLE ARM, INTERFACE TILT PLUS INTERFACE & SHOULDER ROTATION (4 DOF)



AN ADDITIONAL DEGREE OF FLEXIBILITY CAN BE ADDED TO THE ITEM G CONCEPT BY PROVIDING A "TILT" ROTATION JUST BELOW THE INTERFACE. FOUR ROTATING JOINTS ARE INDICATED FOR THE CONCEPT. TILT ROTATION OF $\pm 45^\circ$ IS RECOMMENDED

(H) TELESCOPING SINGLE ARM PLUS 4 ROTATING JOINTS (5 DOF)

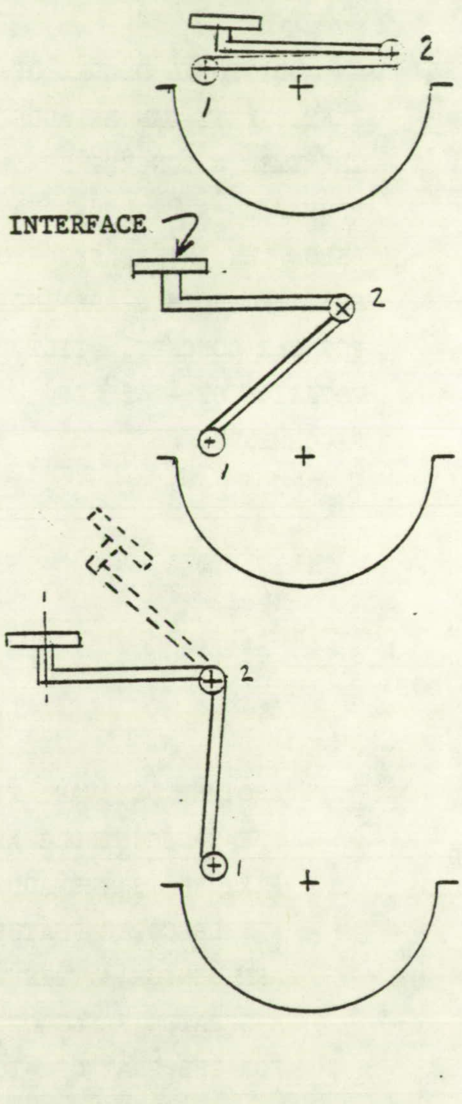


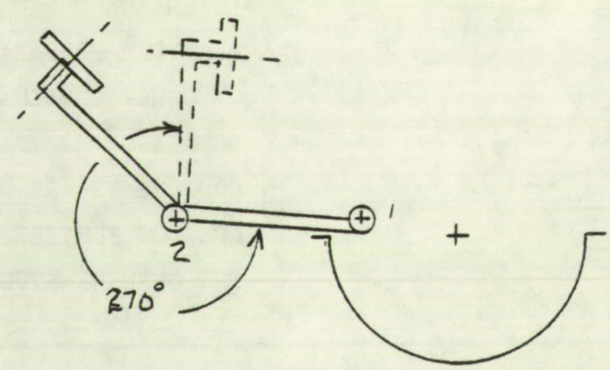
ANOTHER DOF VARIATION FOR THE BASIC SINGLE ARM FIXTURE IS THE ADDITION OF A TELESCOPIC FEATURE TO THE ARM DESIGN. THIS WILL ALLOW A GREATER RANGE OF LOCATION FOR THE PLATFORM-TO-FIXTURE INTERFACE DURING THE PLATFORM PREPARATION.

OTHER COMBINATIONS OF ROTATING AND TRANSLATING COMPONENTS ARE POSSIBLE BUT ARE NOT FURTHER ANALYZED IN THE CURRENT STUDY

Figure B-3 (Sheet 3 of 3)

(A) DOUBLE ARM - STOWED & DEPLOYED
(2 DOF)





JOINT 1 - SHOULDER
JOINT 2 - ELBOW

THE FOUR SKETCHES SHOW THE 2 ARM, 2 DOF FIXTURE IN 4 DIFFERENT STOWED AND DEPLOYED POSITIONS. THE MAJOR DIFFERENCE BETWEEN THIS CONCEPT AND THE SINGLE ARM SIMPLE DESIGNS IS IN THE LONGER REACH POSSIBLE OUTSIDE OR ABOVE THE ORBITER PAYLOAD BAY.

INTERFACE POINTING LIMITATIONS ARE EVIDENT WHEN NO ROTATION OF THE "WRIST" JOINT IS ALLOWED.

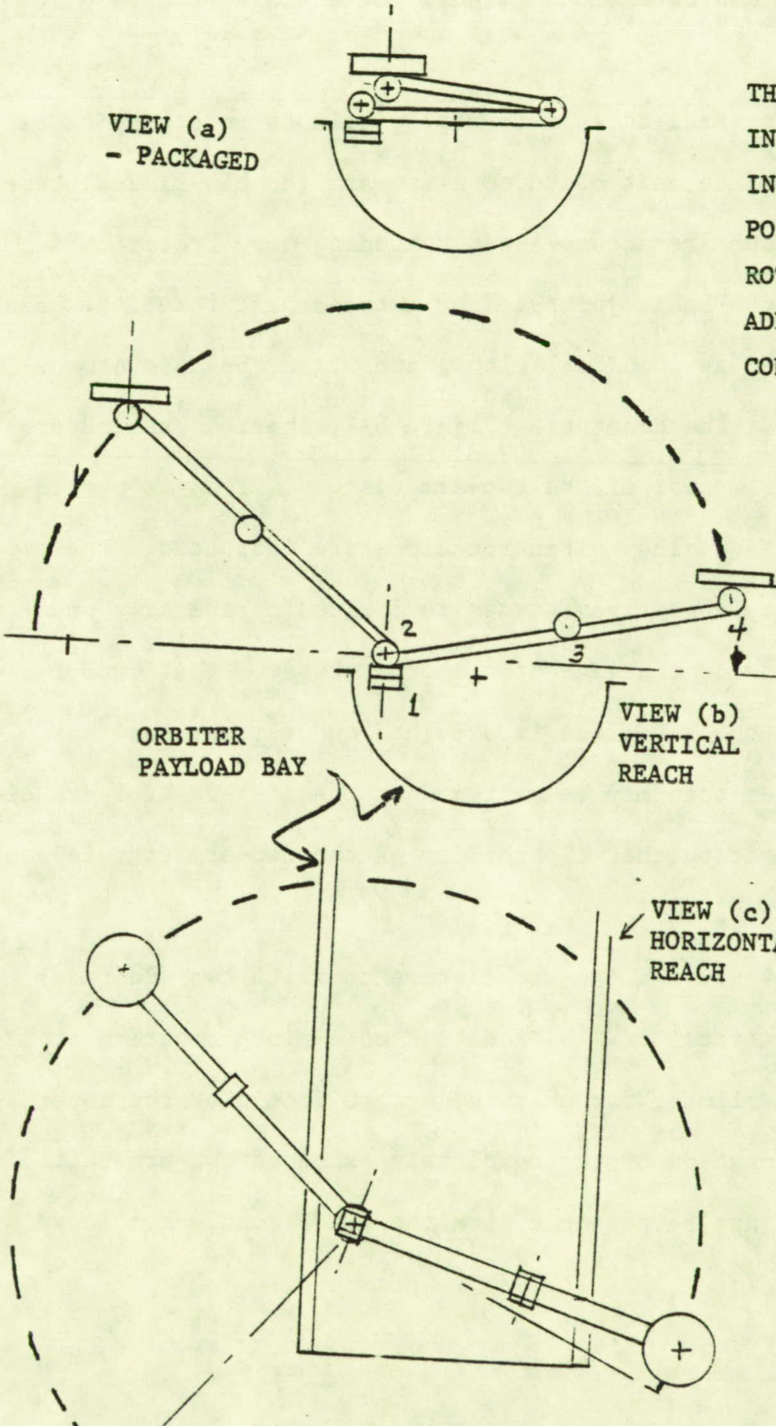
THE RANGE OF INTERFACE POSITIONING SHOWN ON THE SKETCH WILL REQUIRE ~180° ROTATION OF JOINT 1 (SHOULDER) AND ~ 270° OF JOINT 2 (ELBOW). RELATIVE RATIOS OF LENGTH OF UPPER AND LOWER ARM TBD. 3M (10 FT) LOWER AND 2.7 M (9 FT) UPPER LENGTHS SHOWN.

(Sheet 1 of 2)

Figure B-4. Single-Point, Double-Arm Construction Fixture Variations

(B) DOUBLE ARM FIXTURE (4 DOF)

4 DOF:
1. SHOULDER ROTATION
2. " PITCH
3. ELBOW PITCH
4. WRIST PITCH



THIS SHEET OF FIGURE A-4 INDICATES THE EXTENSION OF INTERFACE LOCATION VOLUME POSSIBLE WHEN 2 MORE ROTATION CAPABILITIES ARE ADDED TO THE SHEET 1 CONCEPT.

THE 2 DOF CONCEPT IS LIMITED TO INTERFACE LOCATIONS OF THE VERTICAL SEMI-CIRCLE IN VIEW (b). ADDING SHOULDER ROTATION TOGETHER WITH WRIST PITCH CAPABILITY ALLOWS INTERFACE LOCATION WITHIN APPROX 3/4 OF HEMISPHERE WHOSE RADIUS IS THE SUM OF THE LENGTHS OF BOTH UPPER AND LOWER ARMS OF THE FIXTURE (VIEWS b & c)

ROTATION REQUIREMENTS APPROX:

1 - SHOULDER ROTATION 260°
2 - SHOULDER PITCH 180°
3 - ELBOW PITCH 180°
4 - WRIST PITCH 200°

Figure B-4 (Sheet 2 of 2)

the interface is "above" the orbiter bay mounted base. The height of Concept A would be limited by the orbiter bay with covers and radiators in the closed position. Concept B allows extension of the Y-dimension with a telescoping feature, and Concept C adds an interface rotation capability. The other five concepts (D through H) show increasing degrees of freedom of interface alignment (relative to orbiter RMS operations volume) for a hinged-arm base for the fixture interface.

Figure B-4 develops several cases from most simple to more complex capabilities of a single interface unit based on a two-arm (double-hinged) base. The added degrees of freedom are accomplished by adding more "rotation" joints at one or more of the basic joints. For a two-arm fixture, the "basic" joints are often designated as shoulder, elbow, and wrist, because of the obvious human arm analogy. The Concept A (Figure B-4, Sheet 1) sketches show several positions of the simplest of the two-arm fixture. This is one in which only shoulder pitch and elbow pitch rotations are indicated. The top two of the views show that orbiter bay access is limited by the arms when the interface is kept close to the edge of the orbiter bay. The lower two of the sketches show that the interface is brought "up" further than may be wanted, or "out" further than may be wanted when the fixture arms are clear of the bay. It appears that further flexibility of the two-arm fixture would be desirable.

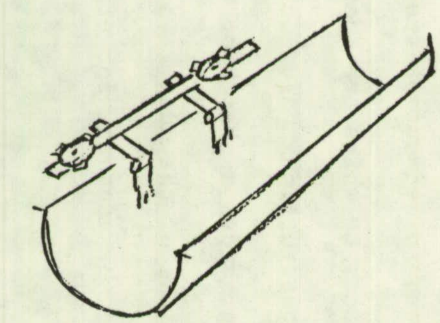
Sheet 2 of Figure B-4 shows a two-arm fixture to which two additional rotation joints are added (total of 4). Addition of a pitch rotation at the wrist area of the fixture allows, for example, upward facing of the interface throughout a 180-degree rotation of the completely extended two-arm unit (see View B). This would not be possible with the 2-DOF double-arm shown on

the first sheet of the figure. The lower view, (C) of Sheet 2, shows the added horizontal area that could be used when shoulder rotation as well as wrist pitch rotation is provided for the double-arm fixture. The addition of these two DOF capabilities clearly improves the flexibility of the two-arm unit. Other rotary and/or telescoping features can be added to the two-arm fixture to improve still more its utility. Each added DOF will, however, increase unit costs and development costs, so further optimization studies will be required relating the specific platform requirements with fixture requirements. Six rotation mechanisms for the construction arm could make it similar to the RMS in capability, with differences being in the arm dimensions.

B.3.2 Multiple-Point Fixtures

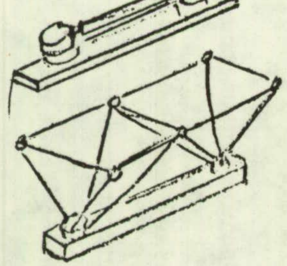
A multiple-point construction fixture is defined as one that provides two or more separated points of contact between the fixture and the platform being constructed. This type of fixture is generally considered a requirement for erectable platform construction. For example, the fixture can hold two platform unions while the strut between the two unions is installed by RMS operations. The simplest multiple-point fixture envisioned would be the two-point fixture, consisting of a beam that could be folded out of the orbiter bay. At each end of the beam would be holding devices to which the "hard points" of a platform structure would be attached during construction and/or during systems installation on the platform. Figure B-5 provides a sketch of the concept together with some comments on the limitations of the idea. Initial analysis indicates that a two-point fixture will not be adequate for efficient construction of erectable platforms.

Multiple-point fixtures can become quite complex by designing capability for three or more point support of the platform and also providing for translating the platform relative to the fixture and, therefore, to the RMS operations



<u>FUNCTIONS</u> - HOLD DEPLOYABLE OR ERECTABLE P/F DURING CONSTRUCTION ACTIVITIES

- o DEPLOYABLE PLATFORM
  - HOLD 2 DEPLOYABLE SECTIONS PRIOR TO JOINING TOGETHER, ADD OTHER DEPLOYABLE SECTIONS AS REQUIRED.



- o ERECTABLE PLATFORM
  - HOLD 2 UNIONS DURING STRUT/UNION JOINING
    - . LIMITED VALUE (?)
  - HOLD ERECTABLE KIT SUBASSEMBLIES DURING ERECTABLE P/F CONSTRUCTION
    - . THIS TYPE ASSEMBLY REQUIRES SPECIAL END EFFECTOR AND REQUIRES TRANSLATION TO ADD MORE CELLS TO PLATFORM

- o CONCLUSION - NOT PRACTICAL FOR "ERECTABLE" CONSTRUCTION

Figure B-5. Two-Point-Hold Construction Fixture.

volume. The translation operations can include motions in X, Y, and Z directions and rotations of the platform axes relative to the orbiter axes. Conceptual sketches of several of the potential features in multiple-point fixture design are shown in Figure B-6. Other motions could be considered. For example, using a single-arm connection between the orbiter and platform would allow the fixture platform to be oriented vertical (Z-direction platform motion) by use of rotary and/or roll joints in the arm. The platform also could be placed over or across the orbiter bay if desired.

Platform translation on fixtures, such as shown on the Figure B-6 sketches, will allow the assembly of larger platforms under well controlled orientation of the platform with respect to the RMS working volume. The large platform assembly can be accomplished without release of the platform during the platform buildup. This type of fixture allows the installation of several platform unions in the correct geometrical relationship at the start of assembly operations, and provides a reaction force to aid in the attachment of strut ends to the unions.

For platforms of a size requiring more than one orbiter flight to complete assembly, the fixtures can provide the "docking port" for platform rendezvous with the second orbiter mission. In many situations, it may be a significant advantage to allow the major portion of the construction fixture to remain with the partially completed platform. In this case, a disconnect feature must be designed into the construction fixture design. Other construction fixture requirements will be noted in a following section on RMS/fixture combinations.

B.3.3 Orbiter/RMS Capabilities

The packaging of LSS platform components, construction fixture, and platform systems within the orbiter must be accomplished within the limitations of the orbiter payload bay and handling system. The Shuttle orbiter

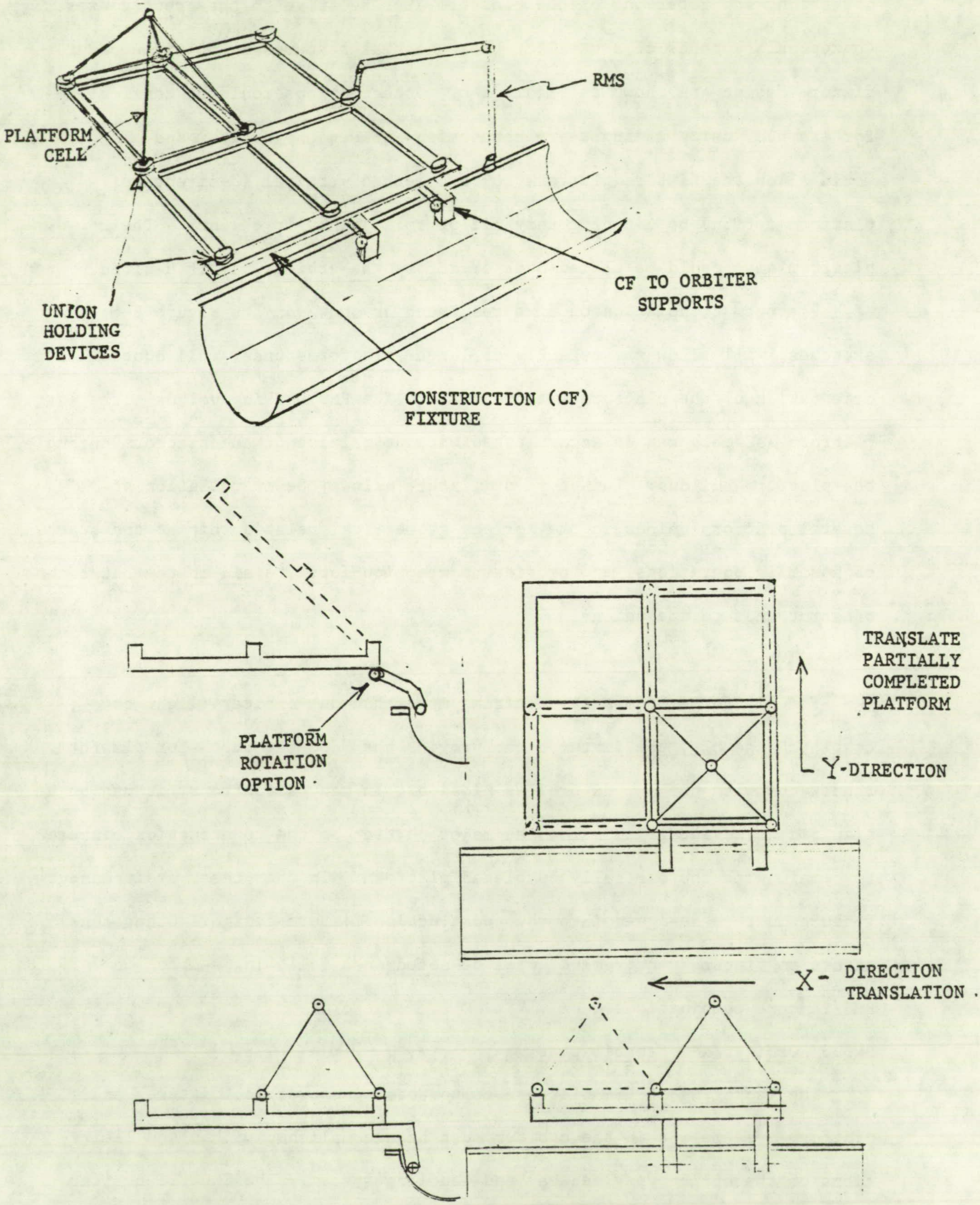


Figure B-6. Multi-Point Construction Fixture Features

basic allowance for the payload volume is an envelope of 4.57 m (15 ft) diameter by 18.29 m (60 ft) long. However, allowances may be needed for orbiter maneuvering systems (OMS) kits if the required platform assembly orbit altitude requires extra propulsion. In addition, access for EVA egress from the cabin airlock must be provided. If the platform assembly requires extended on-orbit staytime (e.g., more than 10 days), orbiter and crew consumables storage may need to be provided in the payload bay. Construction fixture attachment to the orbiter must consider the available structure members and avoid interference with other orbiter subsystem installations. Examples of other subsystems would be the RMS positioner retention mechanisms and the orbiter door hinges.

The RMS basic design and dimensions are shown in Figures B-7 and B-8. It will be noted that the elbow (joint between two longer segments) provides only a single rotation (pitch) and can only bend "down" approximately 160 degrees. This set of limitations has been found to be a constraint on certain types of RMS construction movements. The present study will, however, consider only the standard configuration of the RMS.

Presently developed end effectors are only for use in deploying and releasing payloads delivered to orbit by the Shuttle and, in some cases, retreiving payloads from space and placing them back in the orbiter bay. For example, Figure B-9 shows a cage/probe-wire windup end effector concept. The "snare" type device requires a grapple fixture on the payloads to be handled. This system is not believed to be practical for LSS space construction operations. Therefore, special RMS end effectors will be required for space construction. Requirements include grasping various diameter tubular structure (struts), grasping irregular shaped objects such as platform unions, unlatching flight restraint levers, and rotation of threaded connectors. Several

Reference A, p. 8-15

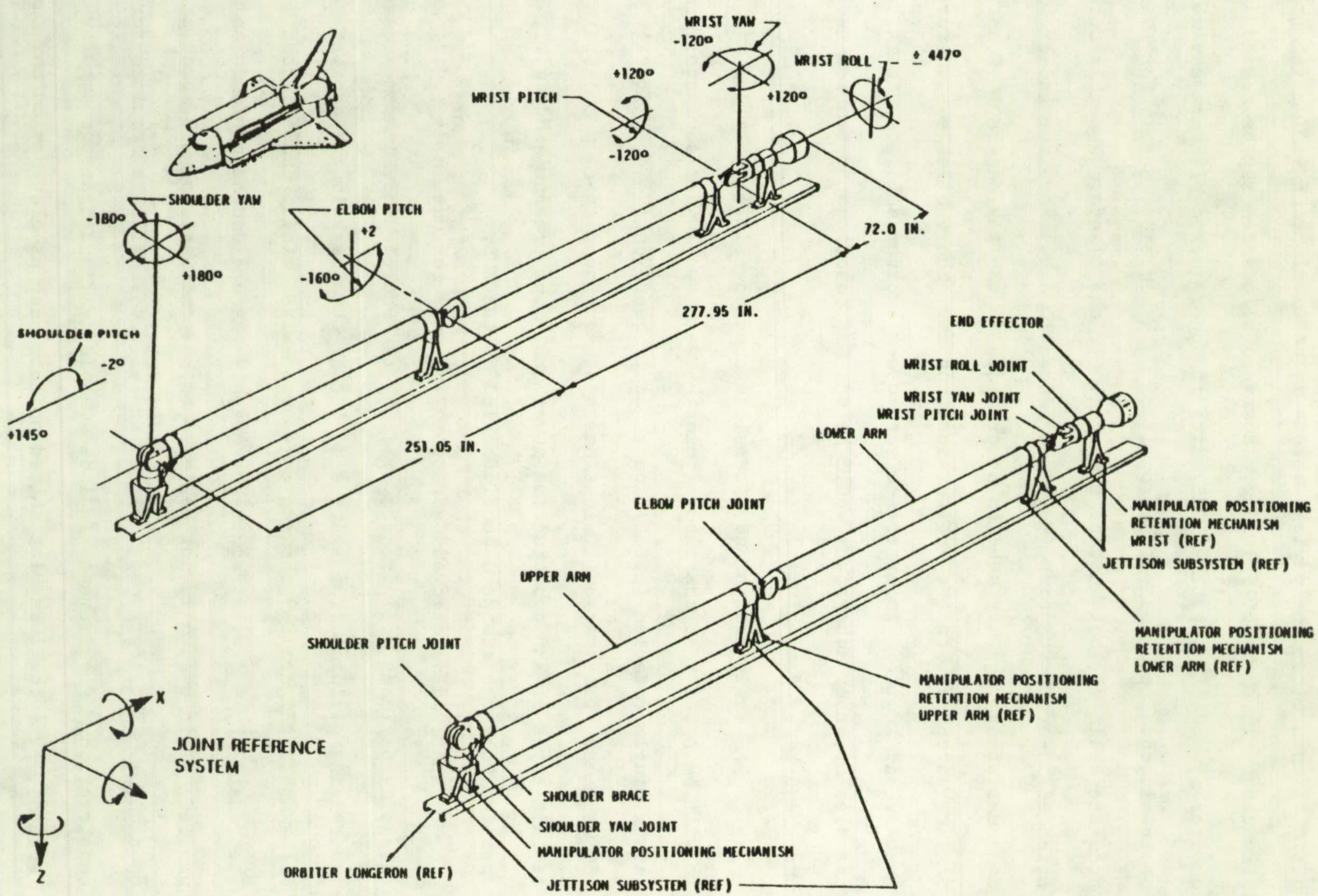


FIGURE B-7. ORBITER REMOTE MANIPULATOR SYSTEM

Reference A, p. 876

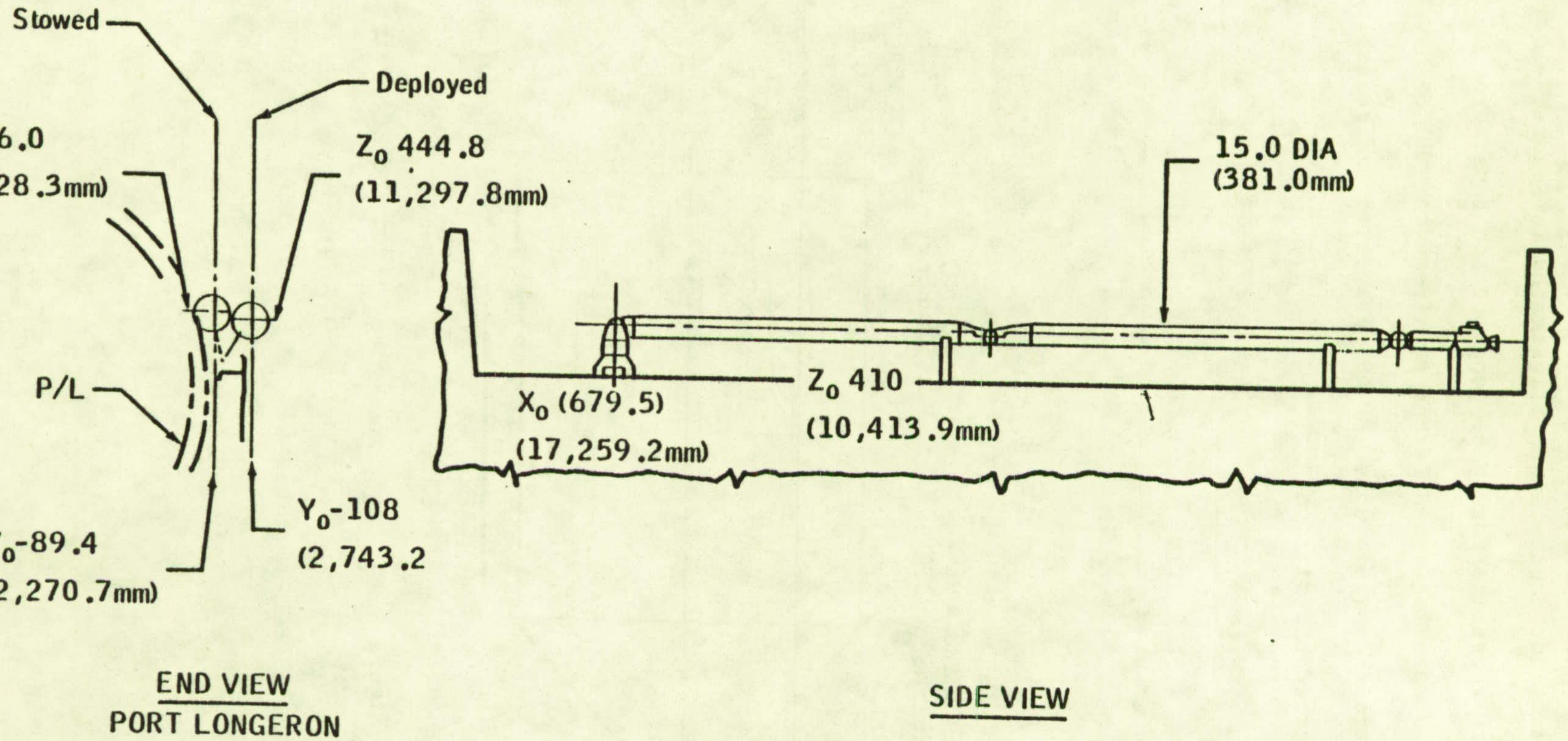


Figure B-8. RMS Location

common end effector concepts are illustrated in Figure B-10. A general concept believed more versatile for space construction considerations is shown in Figure B-11. Detailed end effector requirements will be developed during the later detail design studies of LSS platforms and assembly procedures required for the selected LSS mission.

(Ref. B, p.4-2)

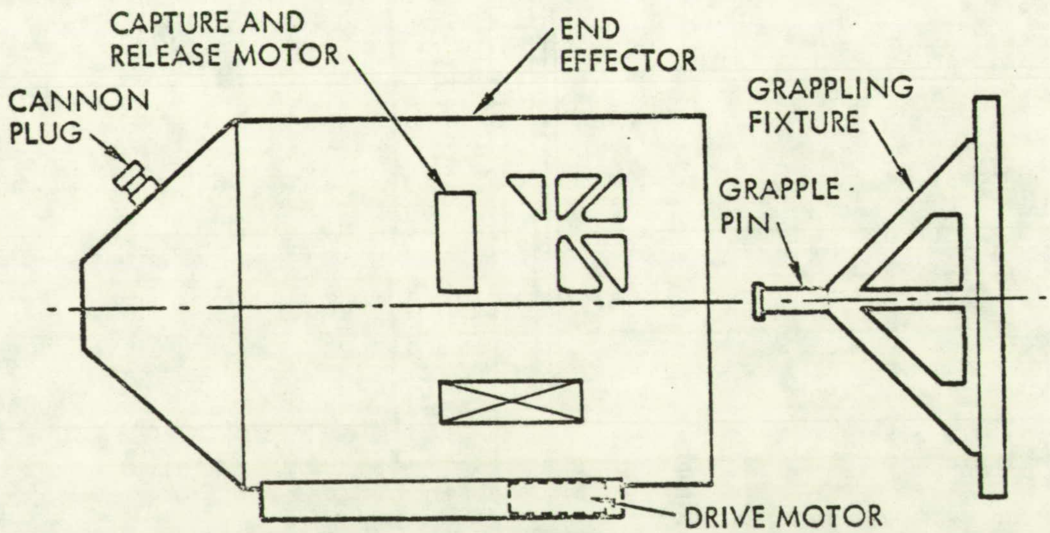


Figure B-9. Cage/Probe-Wire Windup End Effector

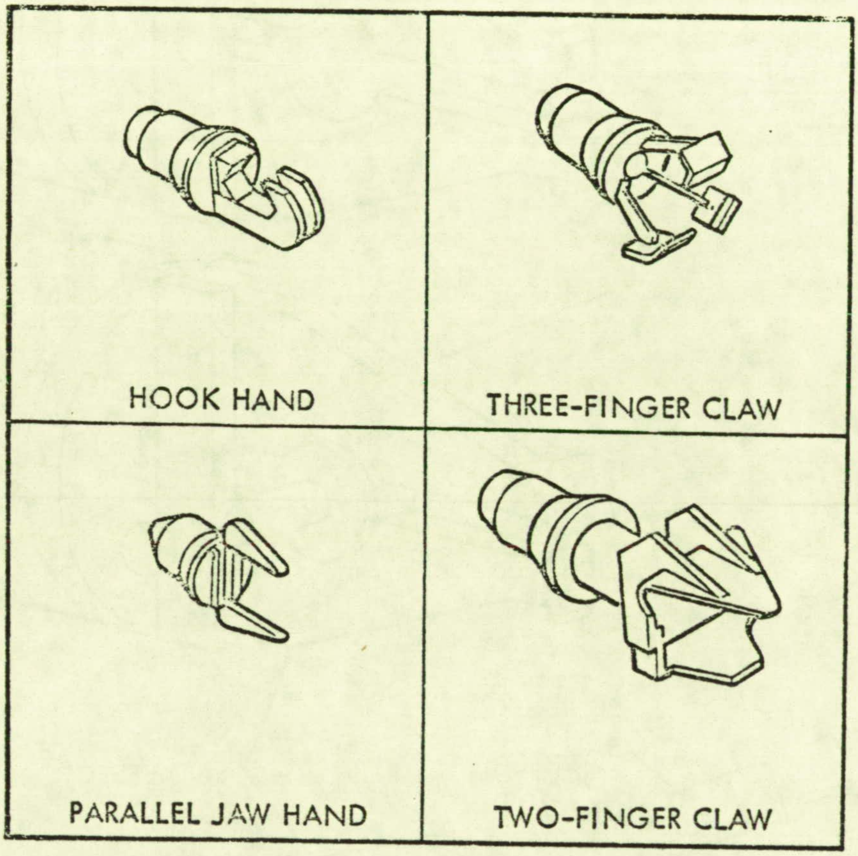
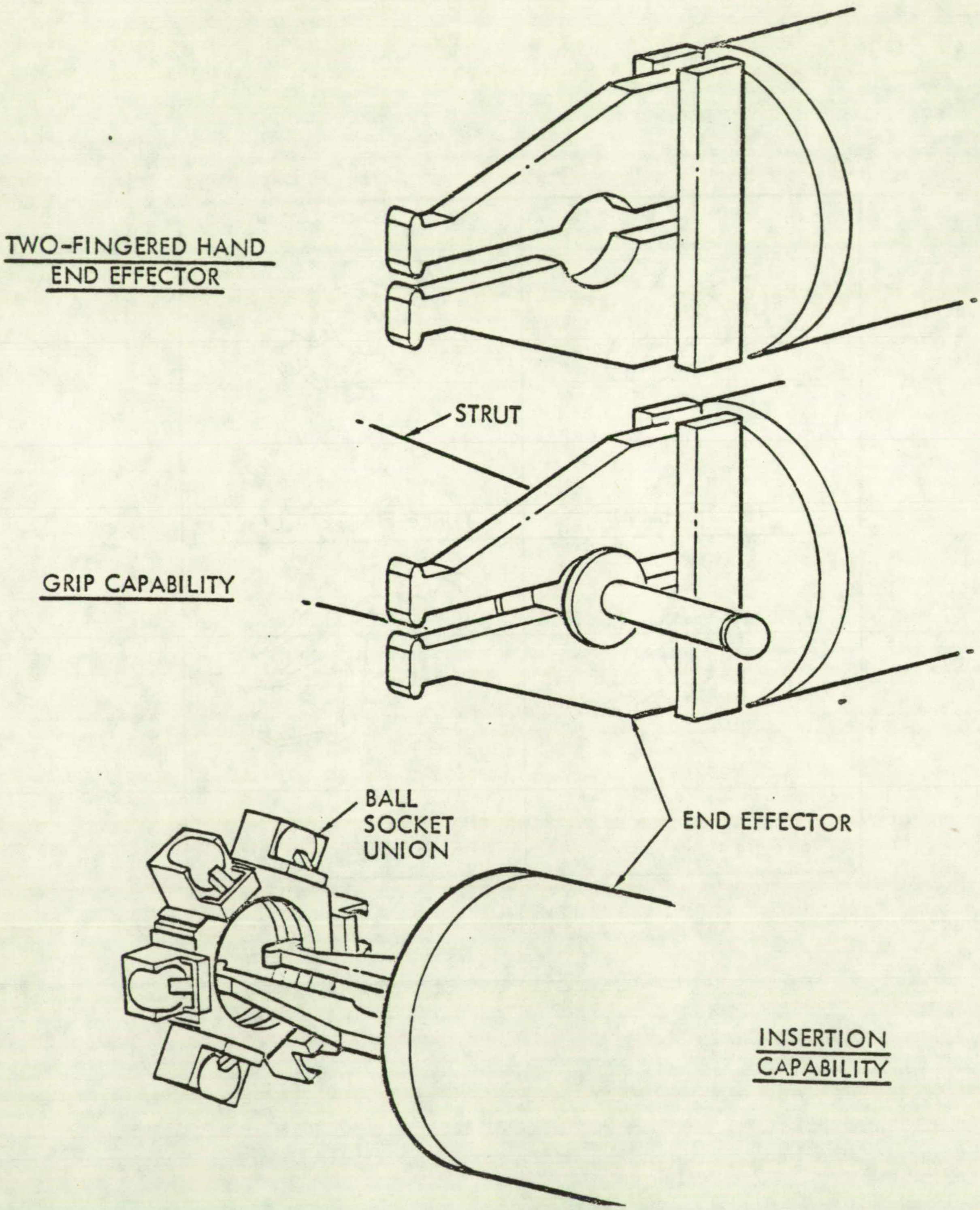


Figure B-10. Prehensile End Effector Concepts

(Ref. B. p.4-4)



(Ref. B, p. 4-14)

Figure B-11. End Effector Concept for Large Space Structures

RMS control is managed from the aft flight deck of the orbiter by one or two IVA astronauts. Direct visibility of RMS motions is desired, but is limited by orbiter window arrangements. The controls for the RMS are still under development, but four general methods are planned:

- Manual through two 3-DOF hand controllers.
- Automatic mode through the orbiter computer which provides a straight-line path of end effectors between two designated points.
- Single-joint drive mode which also uses RMS software in addition to operator commands.

Various other combinations of manual and automatic and backup modes are to be available. Automatic operations are expected to provide end effector placement within ±2 inches of the desired point (see Reference A, p. 8-3). Manual control can achieve greater accuracy, dependent on the visibility available to the operator. Therefore, construction-type assembly operations using the RMS are considered feasible. Tests at the JSC manipulator development facility (MDF) have successfully accomplished ball/socket-joint assemblies and other system assembly operations.

For a parametric-type analysis, it is of interest to examine the working volume in which the RMS can accomplish assembly tasks. The limit would be a sphere whose radius is the length of the RMS from the shoulder rotation point to the tip of the end effector. Of course, the limitations of the RMS joints and the RMS mounting on the end of the orbiter payload bay will decrease the theoretical working volume to an approximate hemisphere centered about the RMS base. For an assumed dimension of 15.5 m (51 ft) for the RMS base to tip length, the volume is then approximately 7870 m^3 (278,000 ft^3).

The RMS operations relative to a platform will usually involve attachments in a planar surface. The maximum area plane available for RMS tip reach at some distance above the RMS base can be defined by a planar intersection of the hemisphere parallel to the hemisphere base. Figure B-12 shows a plot of the relationship of such circular planes of operations versus distance to the plane for the 15.5-m (51-ft) RMS.

The platform surfaces to be assembled can be of a square or triangular pattern of "cells" which will not occupy the total area of the theoretical circular area available to RMS reach. For example, the science and applications platform model used in an earlier study (Reference C) used a square-pattern surface with struts on 5.5-m (18-ft) spacing. This spacing was based on the use of platform payloads mounted on standard size orbiter pallets. The "fit" of various numbers of square cells in the RMS operating plane is shown pictorially in Figure B-13. An additional 0.3-m (1-ft) allowance was made to the grid spacing to estimate the diameter of the enclosing circle and the related distance from the base. The 3×4 grid and 2×5 grid patterns, shown on Sheet 2 of the figure, were the largest pattern faces which could be reached by the RMS. It should be noted, however, that the RMS base distance from the assumed operating planes were only 23 feet and 13 feet.
These distances are considered too close to the RMS base for essentially "overhead" operations.

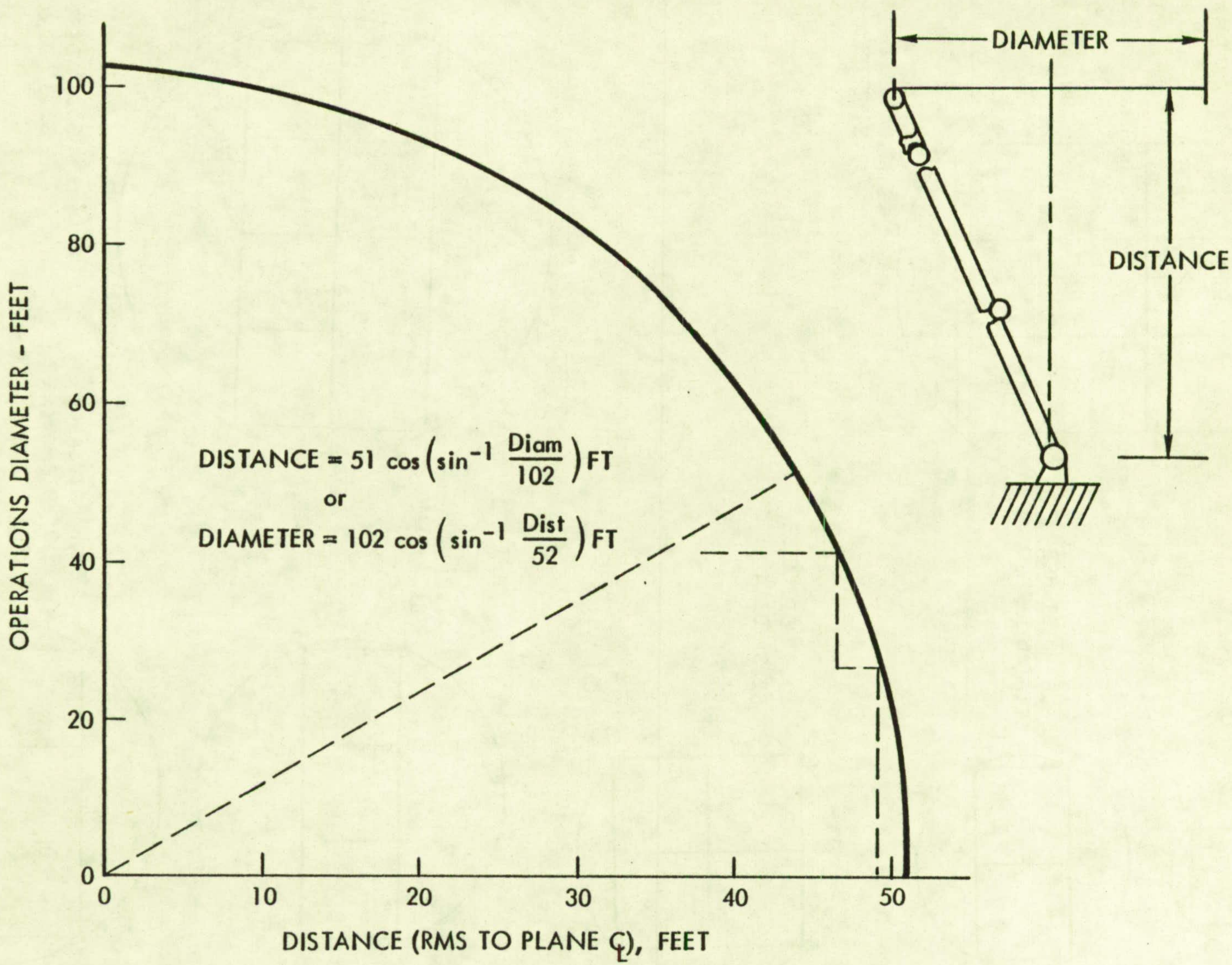
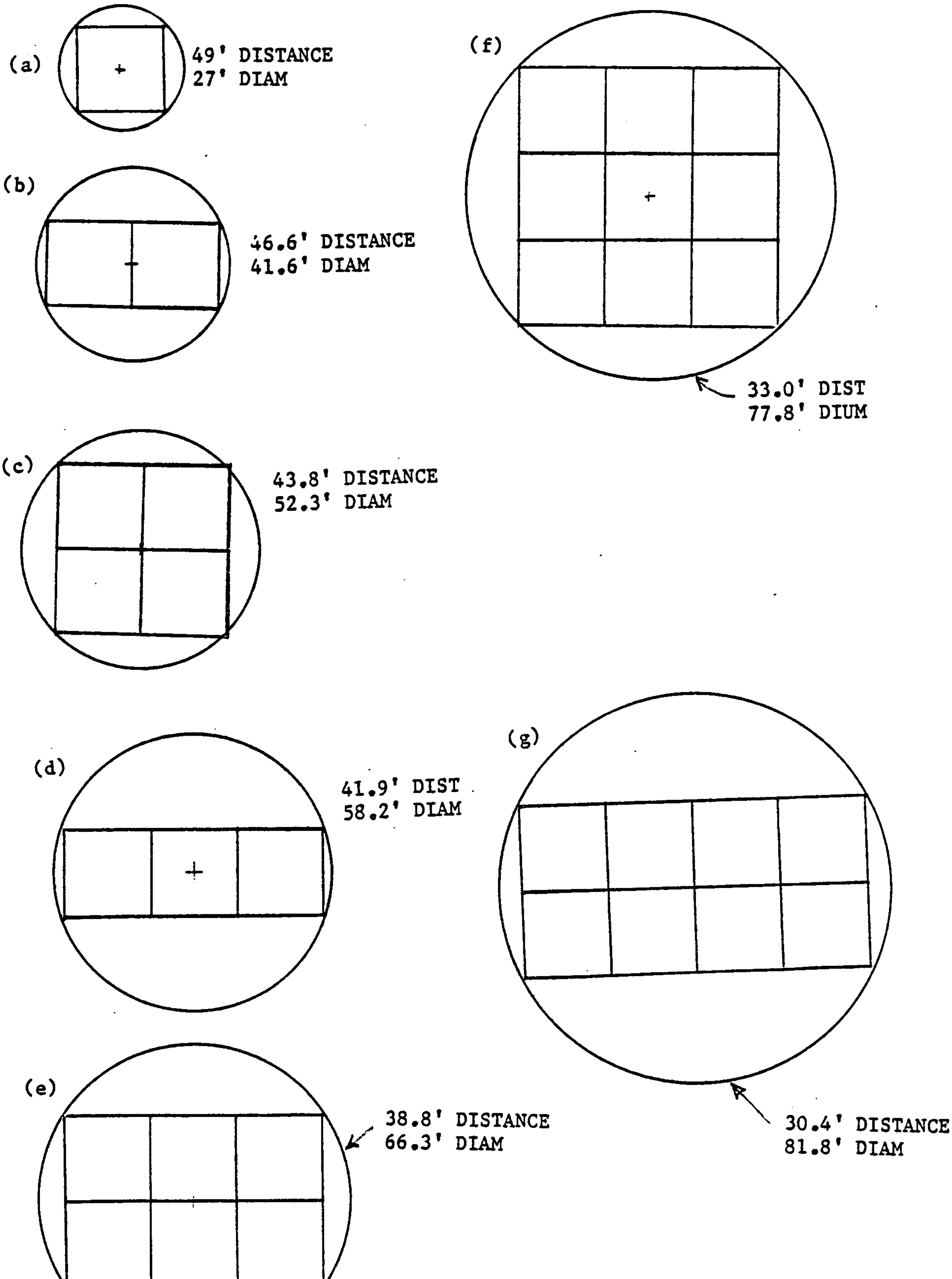


Figure B-12. Assembly Plane Diameter Vs. RMS-to-Plane Distance



(Sheet 1 of 2)

Figure B-13. Platform Fit Vs. RMS Operations

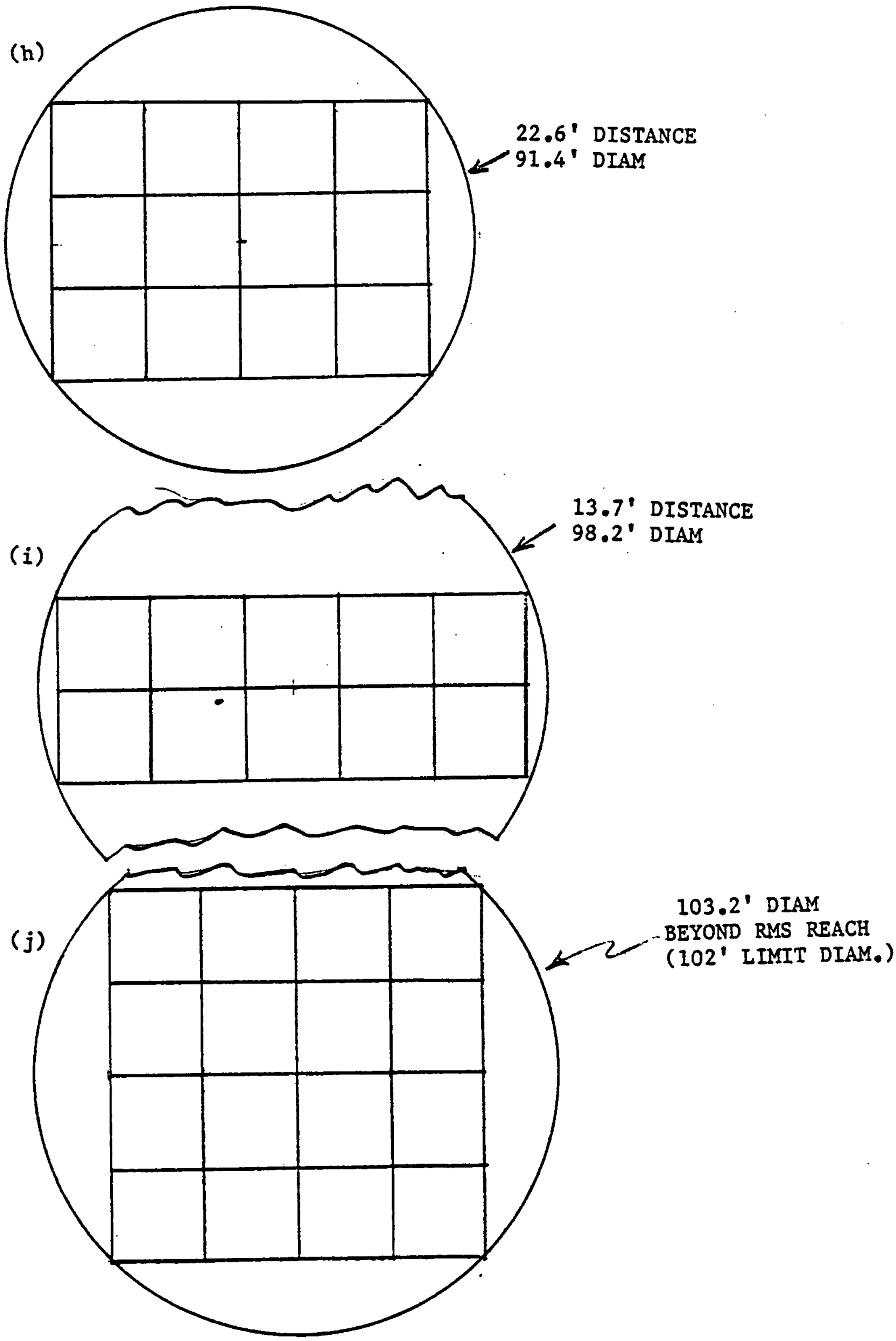


Figure B-13 (sheet 2 of 2)

B.3.4 Fixture/RMS Combination Applications

This section will examine the RMS construction/assembly tool theoretical reach limitations with a modular linear platform and a model area-type platform held in different locations and attitudes by the construction fixture.

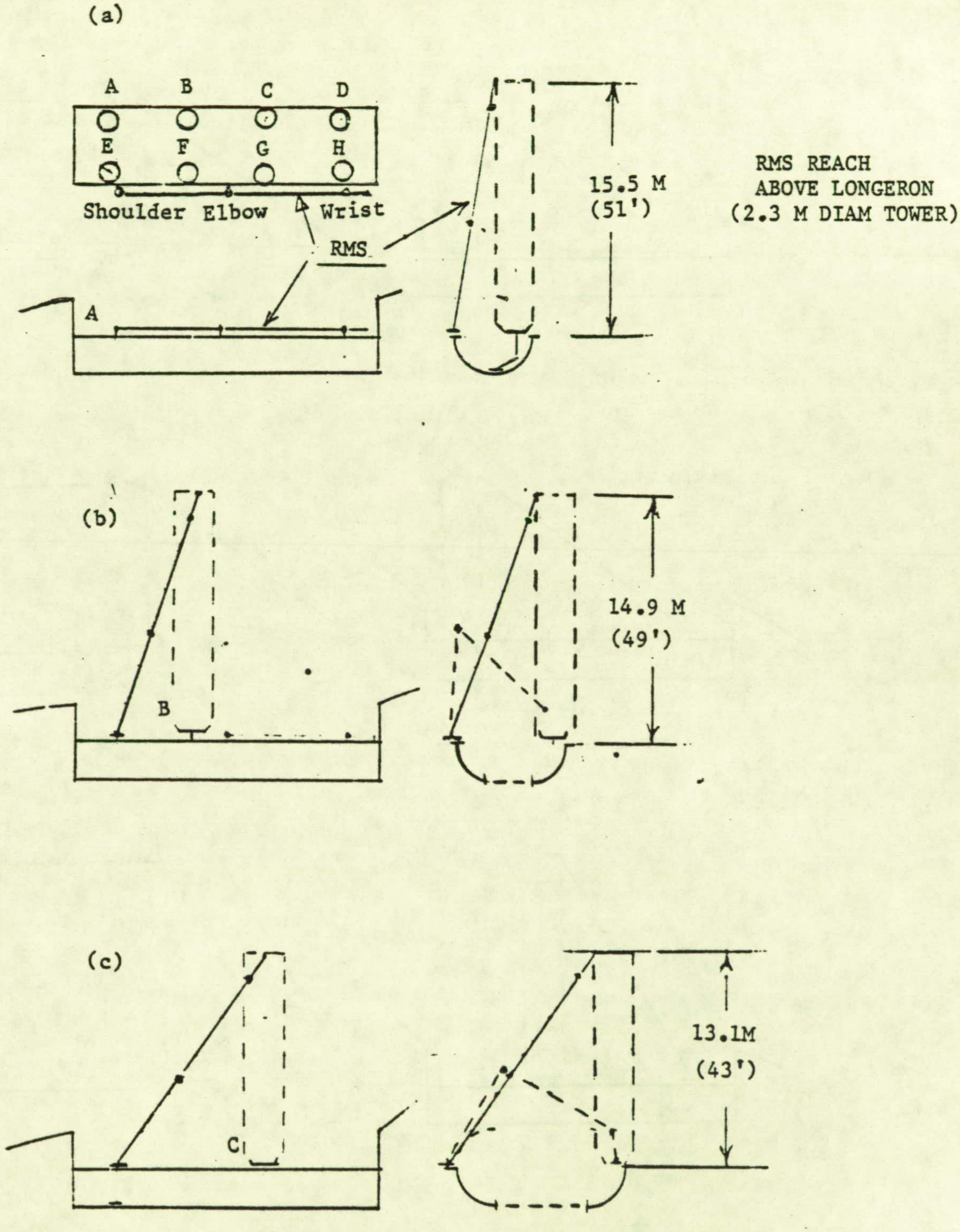
Single-Point Fixture, Linear Platform

The linear platform assumed was a cylindrical "tower" of 2.3-m (7.5-ft) diameter whose base is centered on a simple fixture interface.

Figure B-14 illustrates the graphical analyses performed to establish the reach limits when the fixture is located in several different places inside the orbiter bay. These values varied from 15.5 m at locations A and F down to approximately 9.5 m at location D. The lengths listed were estimated at elevations where the RMS could reach and "touch" the tower. Specific operations required of the RMS during construction and installation operations could, of course, result in variations of the comparison dimensions.

The graphical analysis technique shown on the sketch generally follows the solution of a simple triangle. The base of the triangle is established in a plan view [upper part of Figure B-14 (a)] where the distance from the RMS base to the face of the tower at location B, for example, is measured. This triangle base is then transferred to the end elevation sketch, the lower right of the figure group. The RMS can then be drawn in to scale to see if it can "reach" the particular platform face.

A simple variation of the fixture interface assumed in Figure B-14 is that of providing a built-in "tilt" to the fixture. Figure B-15 shows a sketch in which the location B fixture allows the tower to lean over the orbiter payload bay in the general direction of the RMS base. This orientation provides an 18.3-m reach to the top of the tower, compared with the 14.9-m reach with the tower in the vertical position.



Sheet 1 of 3)

Figure B-14. Fixture Location Effects, Vertical Tower

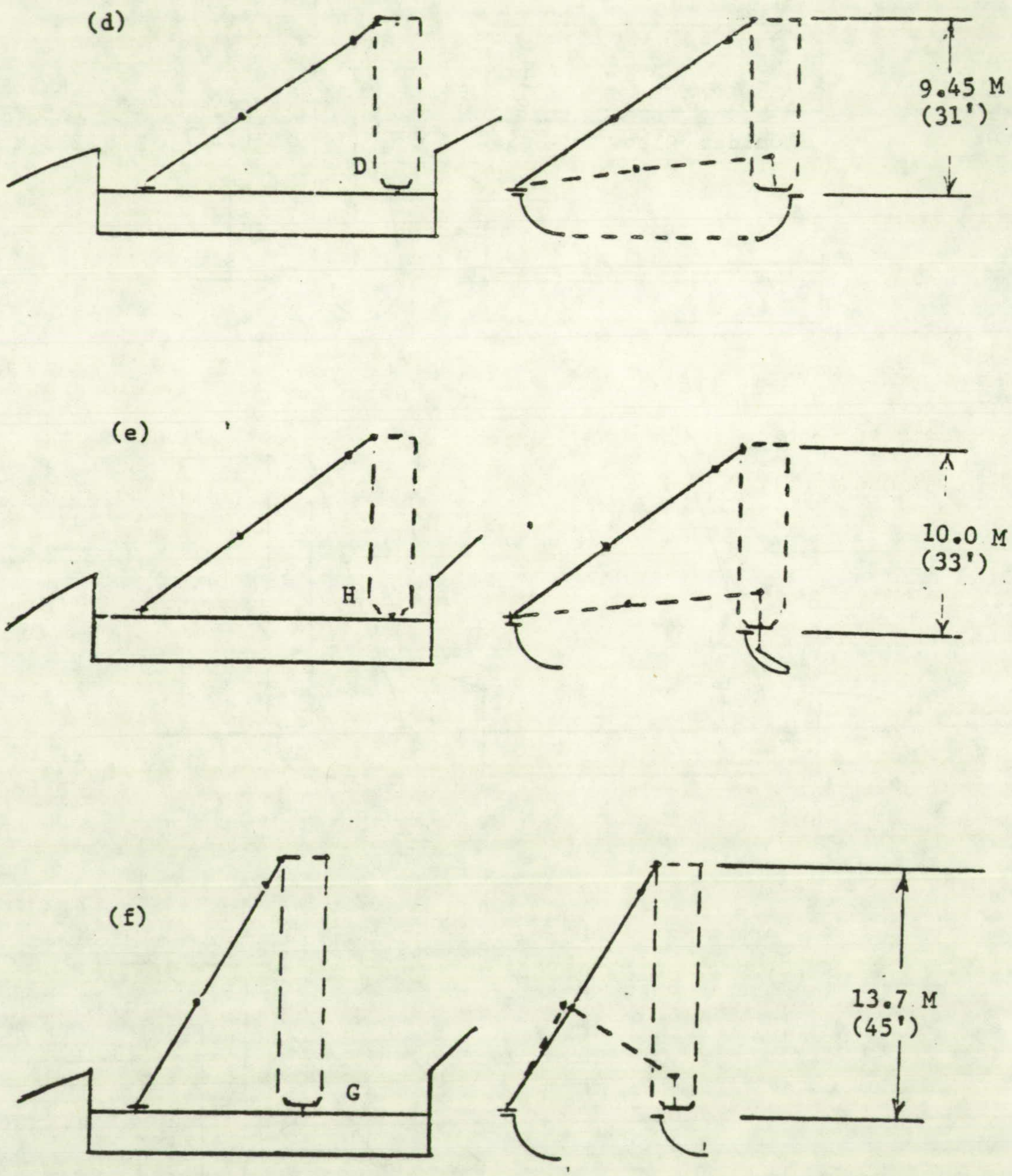
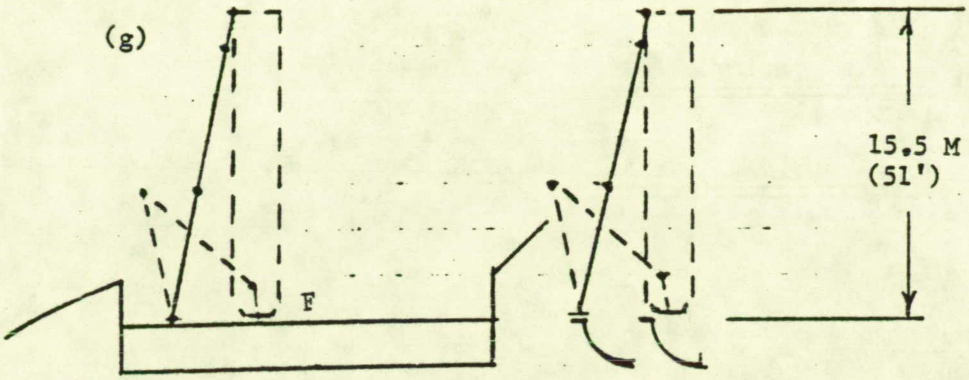
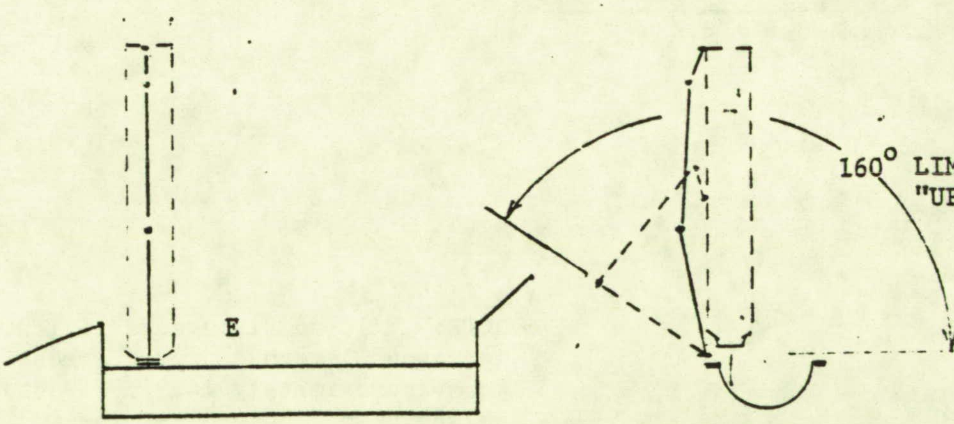


Figure B-14 (Sheet 2 of 3)

(g)

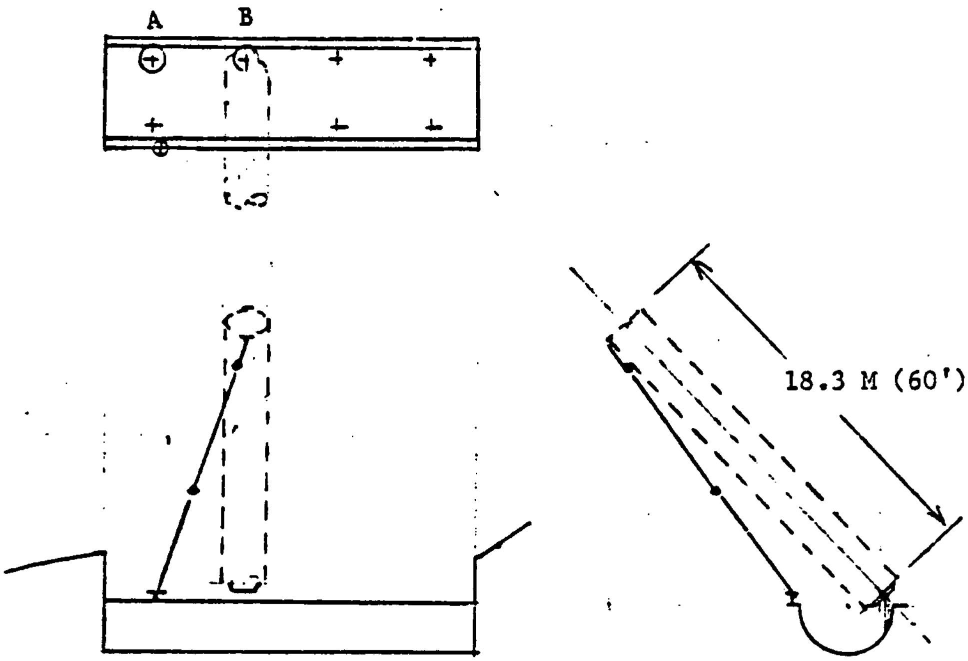


(h)



NOTE: Assumed Location E Considered too close to RMS base. RMS limitations prevent servicing of lower section of tower

Figure B-14 (Sheet 3 of 3)



NOTE: Tilt of fixture as indicated increases length of tower access from approximately 14.9 m (49 ft) as shown on Figure B-14, Sheet 1, to the approximately 18.3 m (60 ft) shown in the above sketch.

Figure B-15. Fixed Fixture Tilt Effects

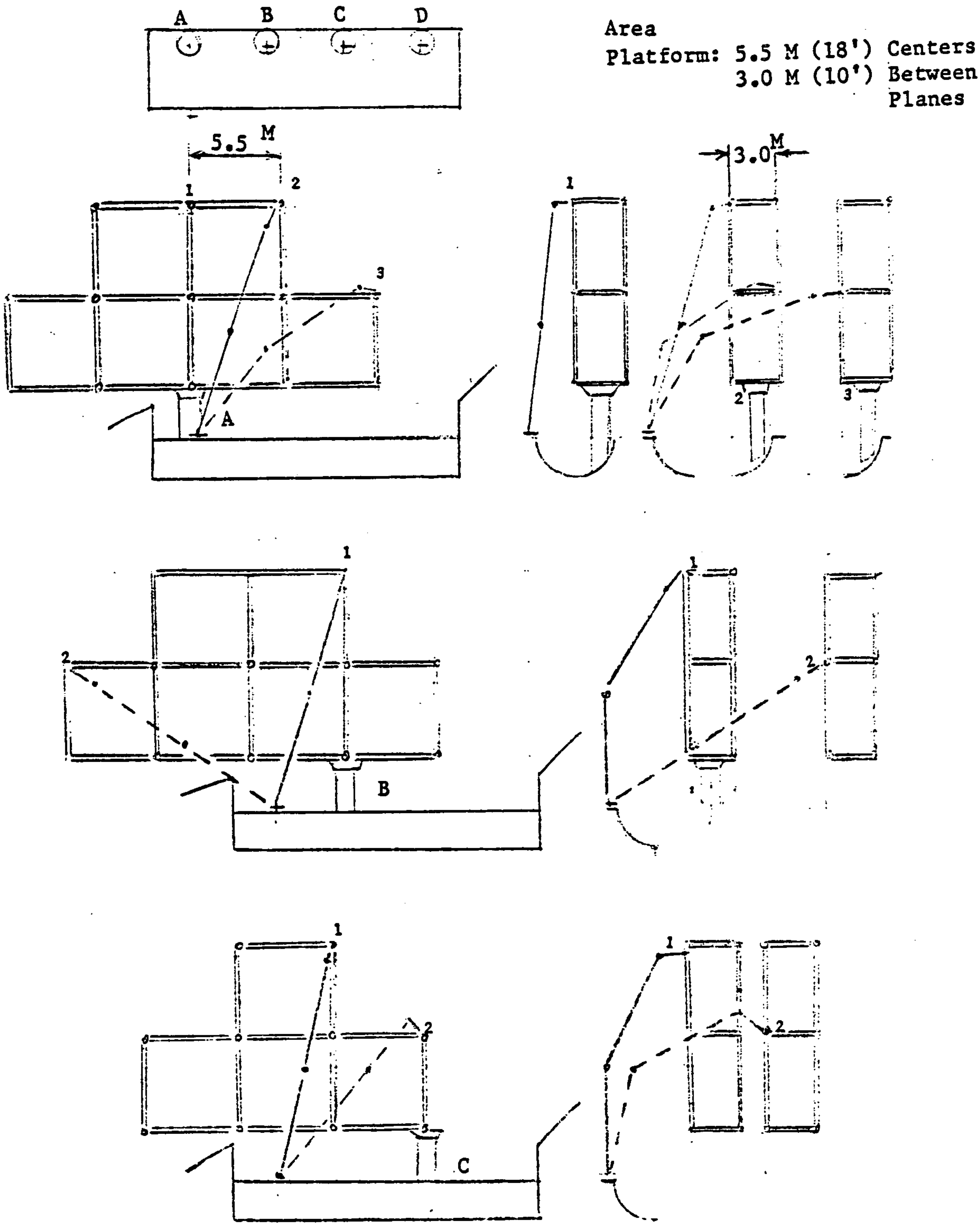
The tower model "reaches" shown in the sketches would provide access to only one side of the tower-type spine for a deployable platform. Providing a simple rotation of the fixture-to-platform interface would allow access to all sides of the platform. Thus, a relatively simple fixture could provide some support for a deployable space platform on which payloads and systems are attached. Having the fixture fixed inside the payload bay will interfere with payload packaging, which may be important for many volume-limited payloads.

Single-Point Fixture, Area Platform

For the area-type platform, the 5.5-m (18-ft) strut spacing square grid platform was selected to provide comparisons for the construction fixture location effects. Figure B-16 indicates platform assumptions used. Here, the platform was assumed to be installed to be in a vertical orientation with the platform face parallel to the X-axis of the orbiter. Platform attachment to the construction fixture was assumed at a lower node which would provide RMS access to most panels of the platform face.

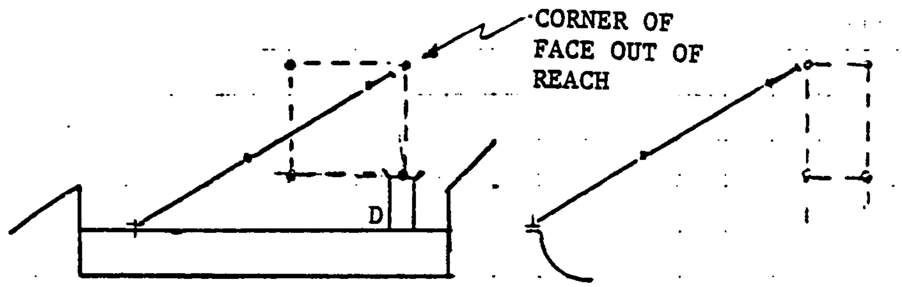
The number of panels which could be completely "touched" by the RMS varied from six for locations A and B, to four for location C, to zero for location D. For this analysis, the construction fixture interface was raised so that the bottom of the platform would be above the orbiter cabin.

A next-variation of the area platform mounted on a simple fixture was to allow the platform to extend (rotate) over the orbiter payload bay. For this set of platform orientations, the platform was installed perpendicular to a line from the RMS base to the center of the simple fixture. The relative positions are shown at the top of Figure B-17. The results from this set of assumptions were six-panel coverage for locations A and B, two-panel coverage for location C, and zero panels again for location D. Results were also



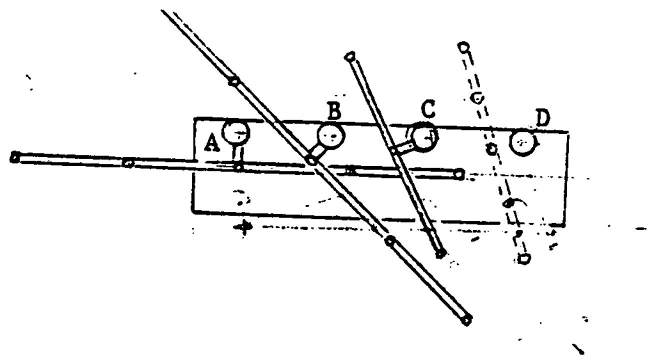
(Sheet 1 of 2)

Figure B-16. Fixture Location Effects, Area Platform

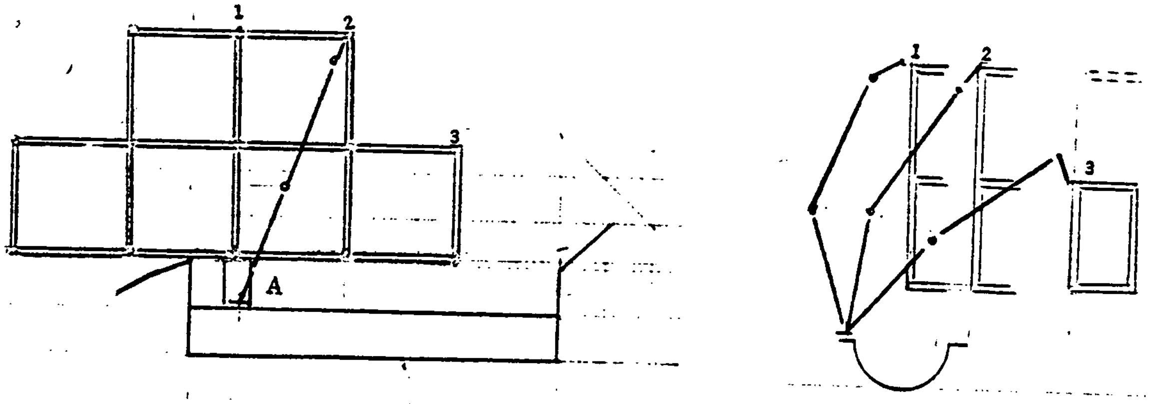


RESULTS:	PLATFORM MOUNT	PANELS IN REACH	COMMENTS
	A	6	
	B	6	
	C	4	
	D	0	

Figure B-16 (Sheet 2 of 2)



(a) Six Panels



(b) Six Panels

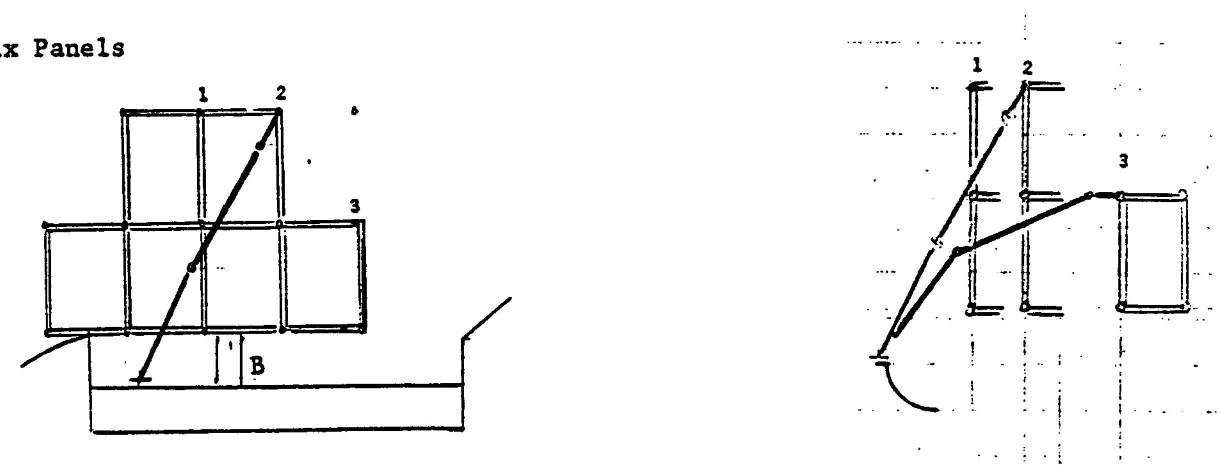


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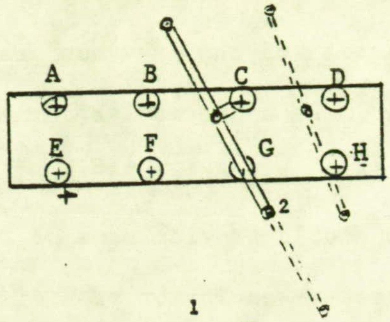
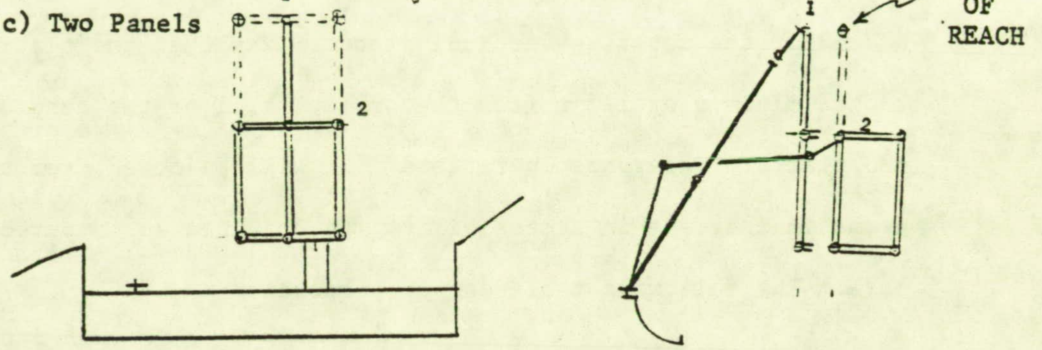
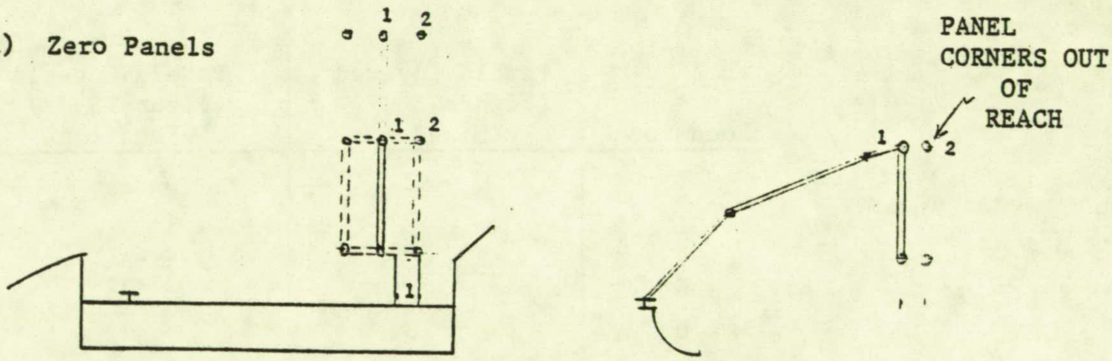
Figure B-17. Area Platform, Vertical over Payload Bay



(c) Two Panels



(d) Zero Panels



SIMILAR SKETCHES FOR PANELS E,F,G,H.

RESULTS:

PLATFORM MOUNT	PANELS IN REACH	COMMENTS
A	6	
B	6	
C	2	
D	0	OUT OF REACH
E	0	TOO CLOSE TO RMS
F	6	
G	2	
H	2	

Figure B-17. (Sheet 2 of 2)

estimated for fixture locations on the same side of the orbiter bay as the RMS. Results are shown in the table at the bottom of Figure B-17.

It can be noted from several of the previous graphical analyses that small dimensional differences could make a particular corner accessible and, therefore, complete another panel of a set. A simple addition of "rotation" of the fixture interface during construction could provide some of this required "closing" dimension. Figure 18 illustrates results of providing this DOF. A ground rule added for the rotating vertical platform was that the platform faces would be kept a minimum of 1.5 m from the orbiter tail or the base of the RMS during the RMS/platform interface operations. It will be noted from the figure that a dramatic increase in accessibility was obtained as compared with the previous case. The following table compares results.

Location	Panels Covered (Figure B-17) Fixed	Panels Covered (Figure B-18) Rotation
A	6	8
B	6	9
C	2	12
D	0	12
E	0	0
F	6	TBD
G	2	12 (est.)
H	2	12 (est.)

The rotation of the interface is therefore indicated as of very significant value. Time to rotate the platform could be a factor requiring analysis as well as the interference with access to the orbiter payload bay.

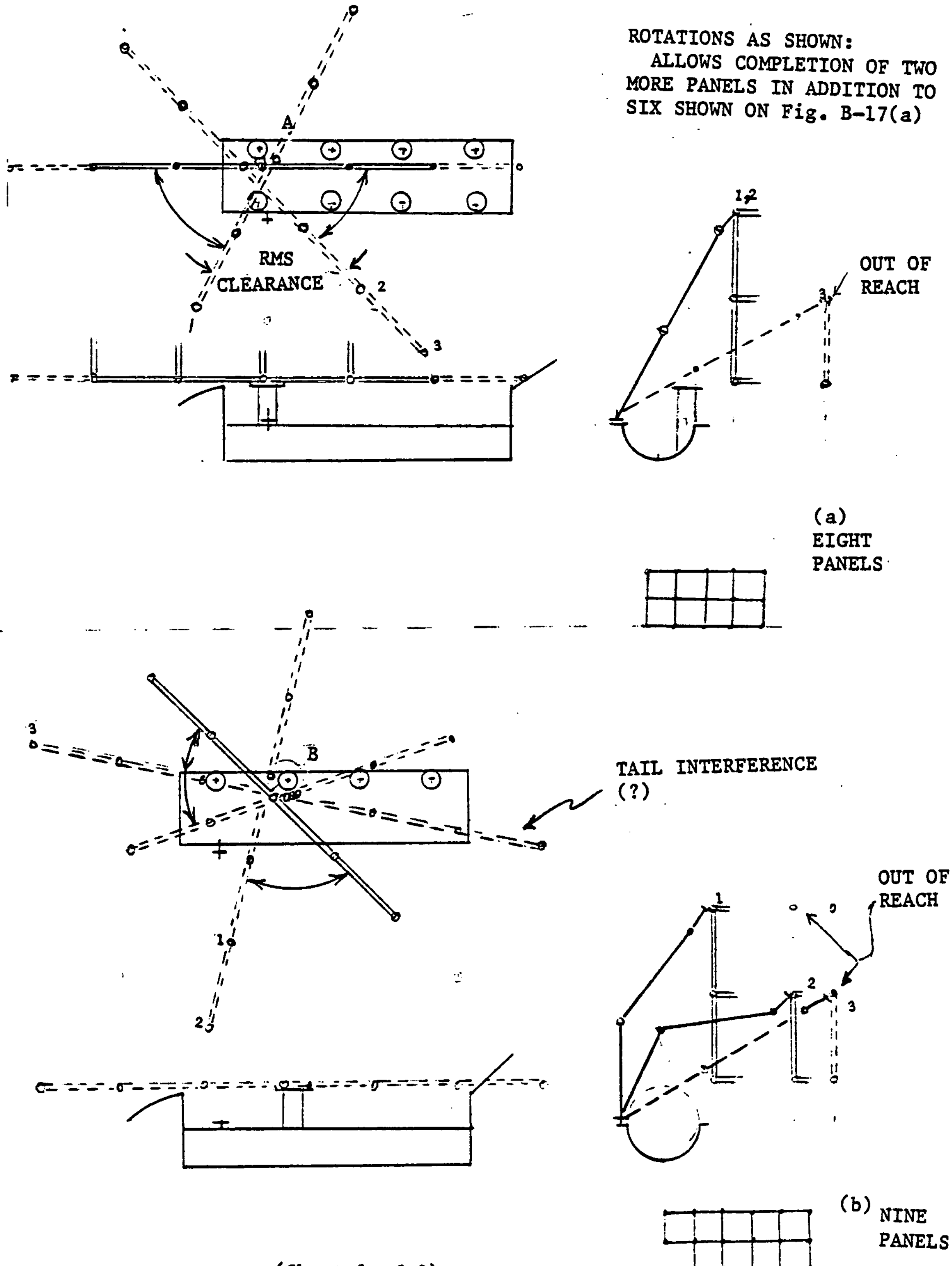


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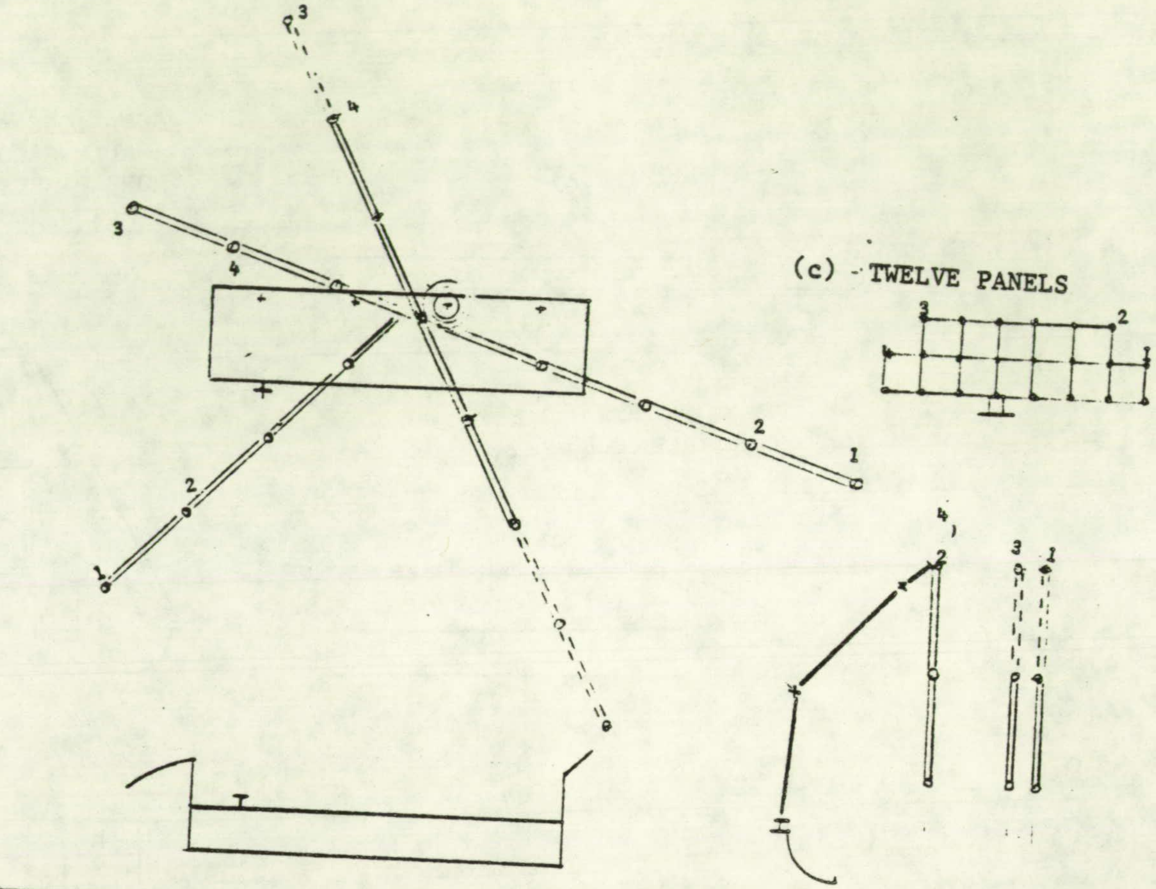
Figure B-18. Area Platform, Vertical with Rotation



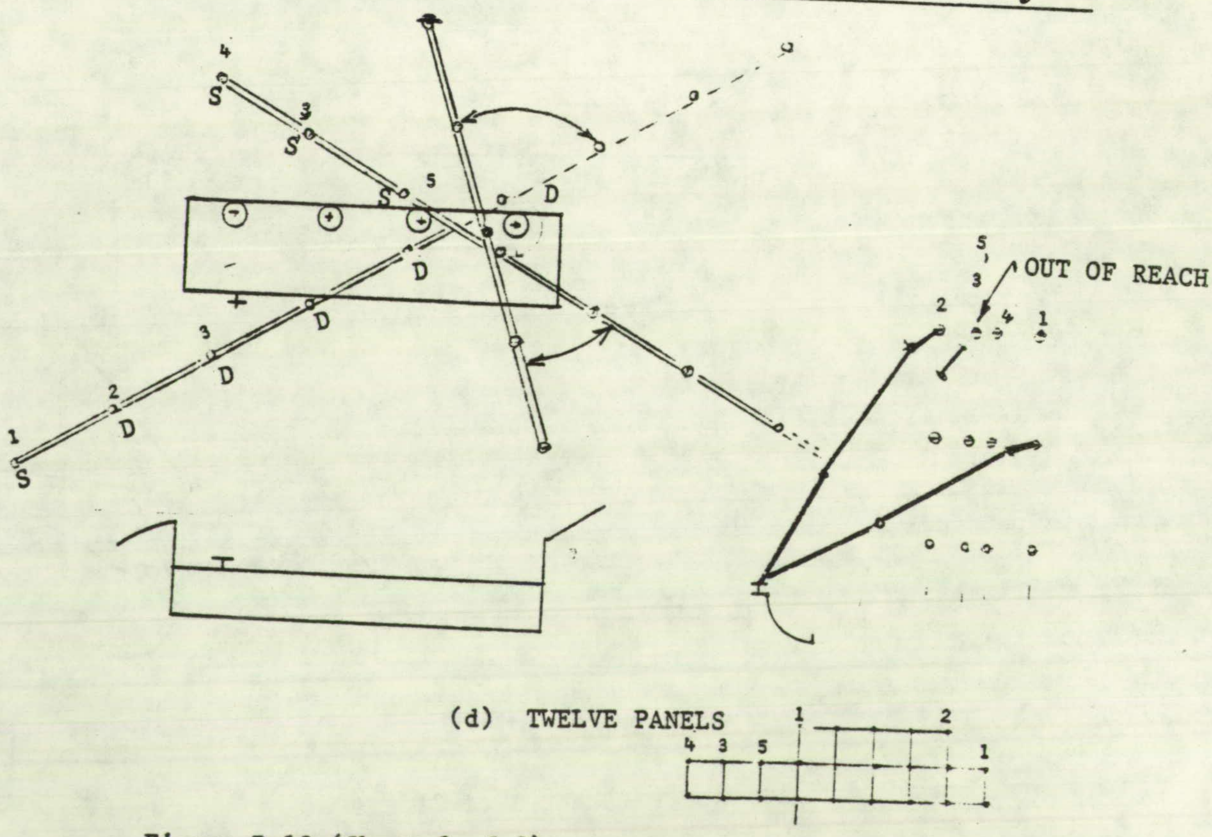


Figure B-18 (Sheet 2 of 2)

Figure B-19 shows the layout of the largest platform that can be serviced from a fixed interface in a typical overhead orientation. This was established in Figure B-13h. The B-19 figure shows some of the complexity of RMS access to the near-center section of the platform when the platform is close to the base of the RMS. Here again, additional maneuverability of the platform relative to the RMS appears as a requirement.

Figure B-20 provides an estimate of the largest area platform coverage to be obtained from a single-point fixture with a rotation interface. The center of platform rotation is placed at the maximum reach of the RMS (with working clearance below the platform). The periphery of the platform circle is defined by the maximum reach of the RMS 180 degrees from the reach toward the platform center. The maximum platform area shown on Figure B-20 would thus provide area for an estimated 60 panels, as compared with the previous maximum of 12 panels. The attainment of a deployable platform of the size indicated in a single orbiter launch package has not been analyzed. The Figure B-20 illustration does, however, serve to indicate an upper limit for the simple, single point assembly fixture and RMS reach combination. If the platform size and packaging require the joining of two or more sections, a more detailed analysis of total operations and size limits would be required.

Multiple Point Fixture, Linear and Area Platforms

The multiple point fixture concept selected for this portion of the subject analyses was that of the 5.5 m square grid to support the erectable area type platform assembly. Figures B-21 and B-22 illustrate the RMS reach capability for various multiples of the square grid spacing.

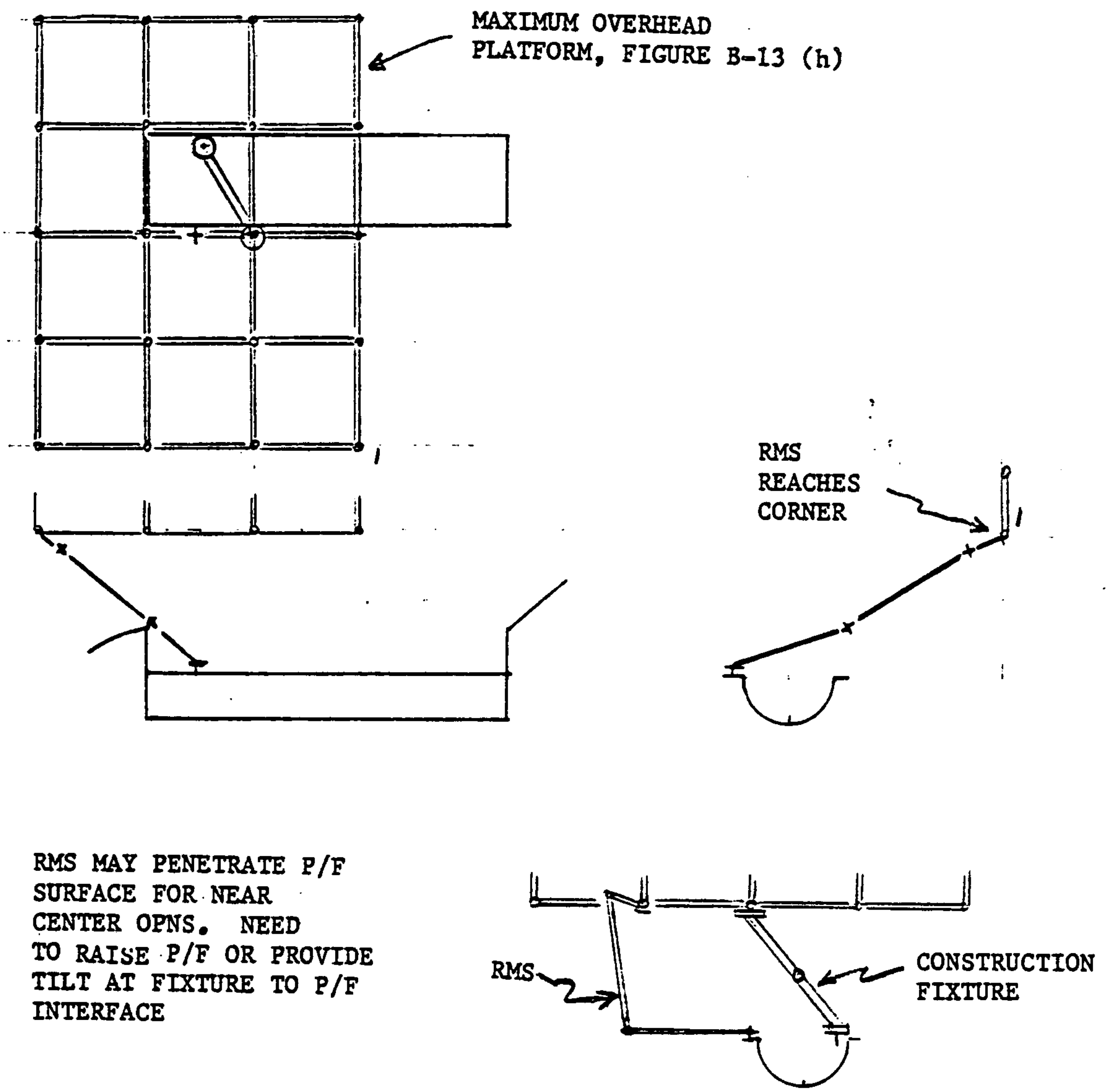


Figure B-19. Overhead Area Platform

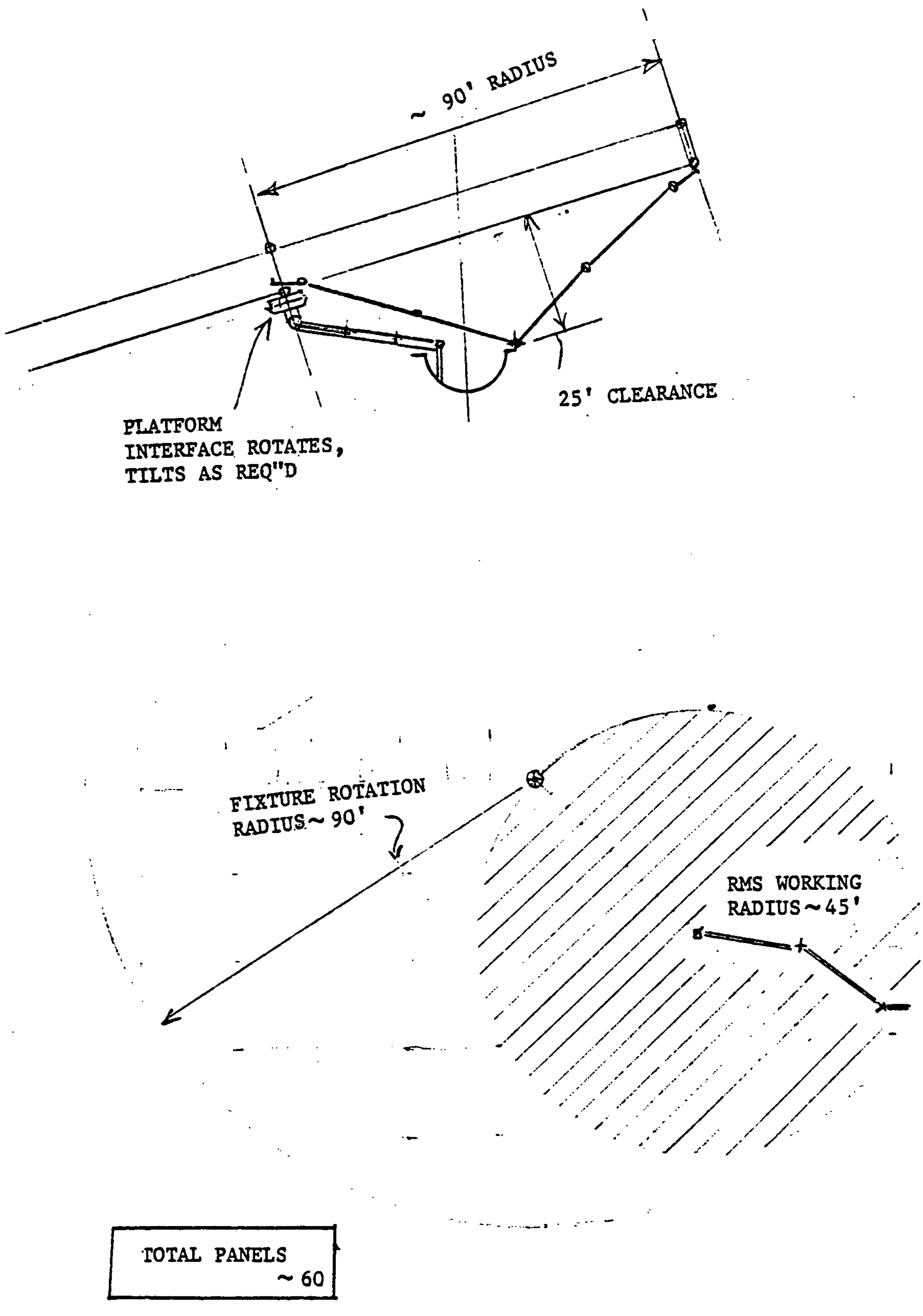


Figure B-20. Overhead Rotating Platform

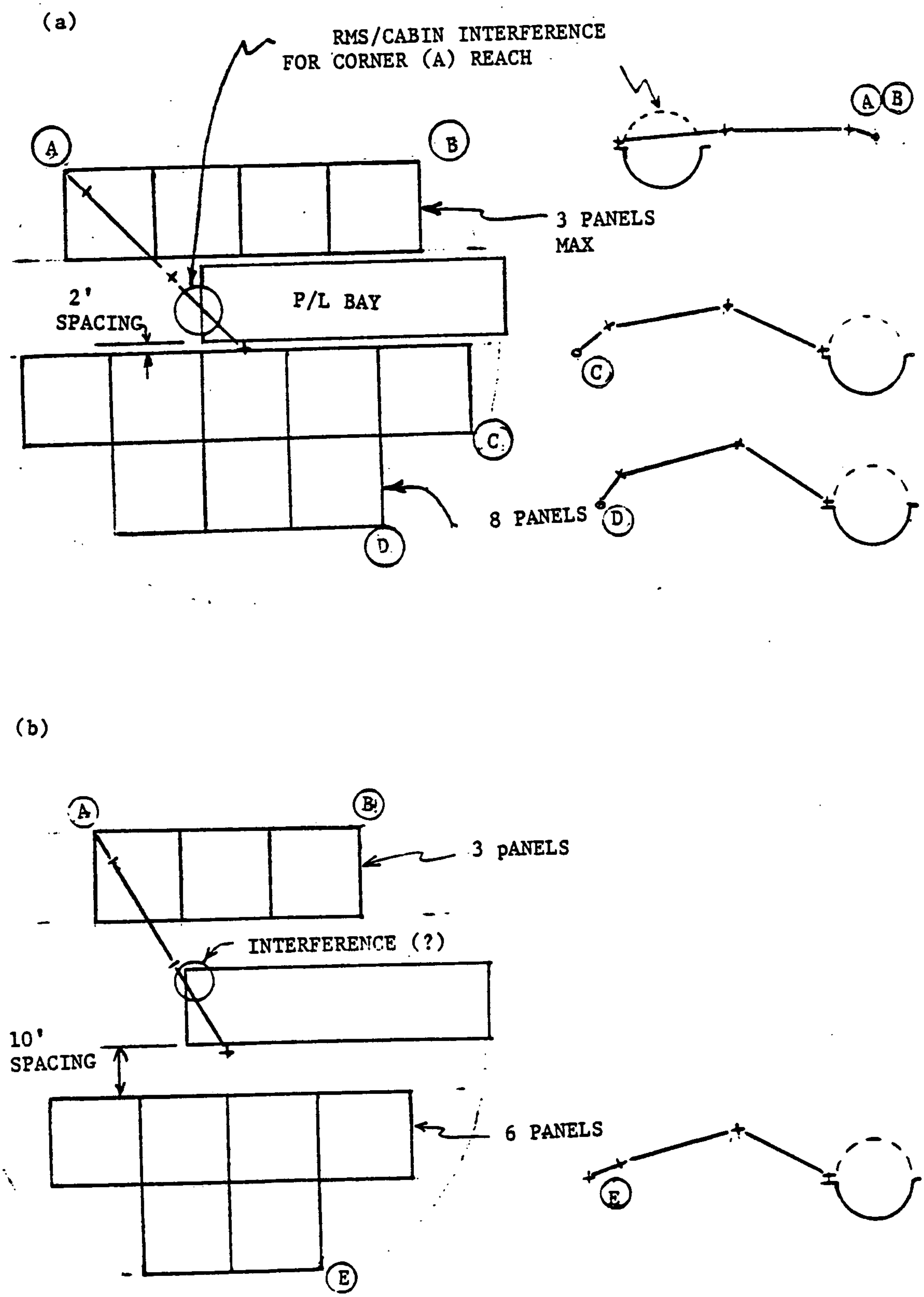


Figure B-21. Horizontal Multi-Point Fixture Capability Vs. Location

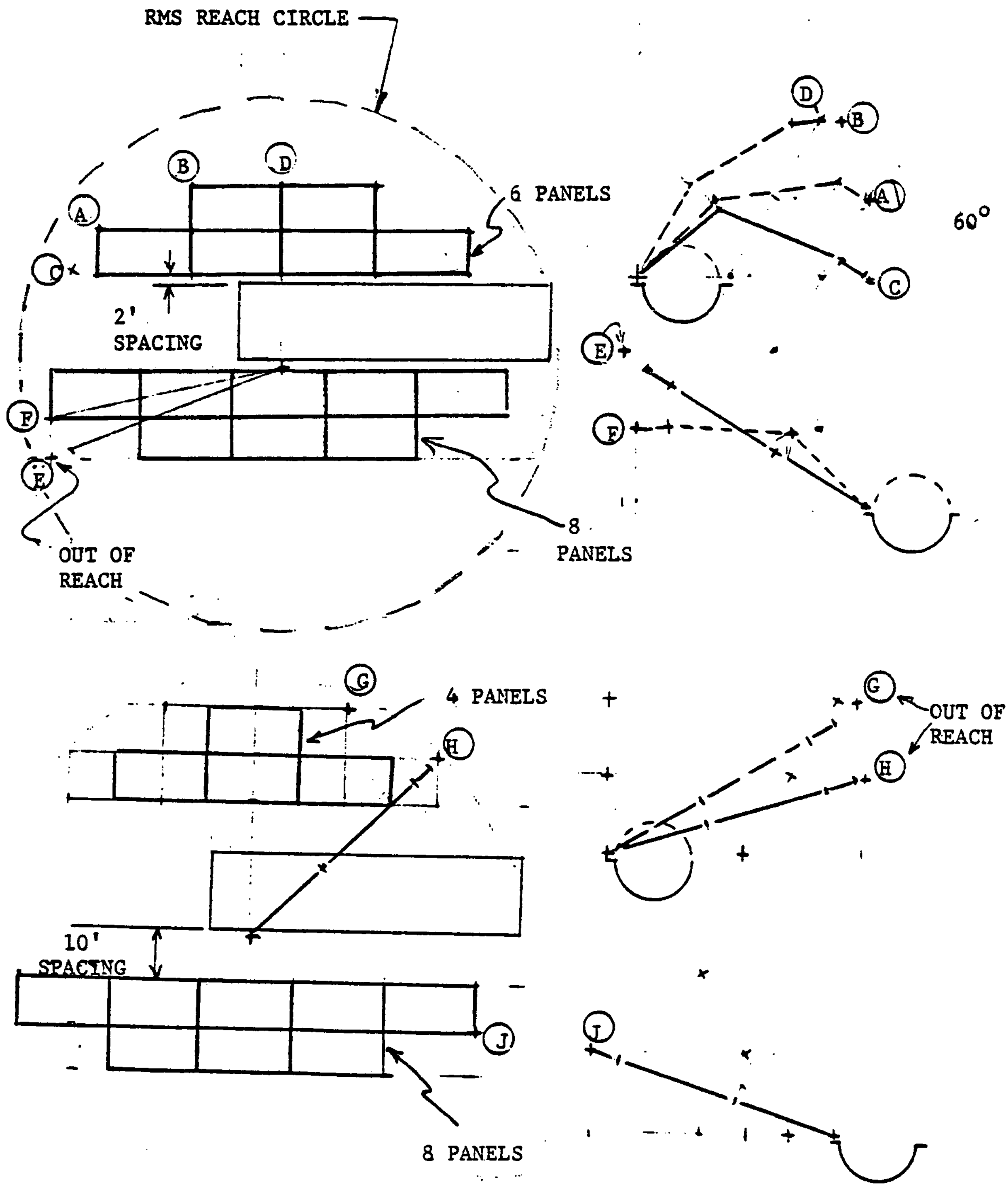


Figure B-22. Inclined (60 Deg) Multi-Point Fixture Capabilities.

The Figure B-21 sketches show the fixture plattern folded out of the orbiter bay on either side of the orbiter bay. Two spacings are indicated, 0.6 m (2 ft) and 3.0 m (10 ft) from the assumed 4.5 m (15 ft) diameter orbiter payload bay. A "horizontal" platform installation is assumed, i.e., the plane of the fixture would be parallel to the orbiter X-Y coordinate plane.

The advantage of the multiple point fixture installation on the same side as the RMS is shown in both the (a) and (b) sections of the figure. For Case (a) the potential of 4 panel reach (far side) is reduced to 3 panels by RMS interference with the orbiter cabin for one panel. Thus for the far side location of the fixture, the RMS can service 3 panels and for the near side location the RMS can service a total of 8 panels.

Figure B-21(b) with the increase outboard spacing of the multipoint fixture indicates that for the far side location the RMS can service 3 panels versus 6 panels for the near side locations. It can be assumed that a linear type platform installation could be assembled on the platform row nearest the orbiter in each of the four alternatives. These applications are then for the case where no capability for platform translation is assumed.

Figure B-22 is a similar set of sketches where the assembly fixtures are inclined at 60 degrees from the horizontal with other assumptions held the same as in Figure B-21. This arrangement increased the far-side capability from 3 to 6 panels for the close-in installation. The other comparisons are shown in Table B-2. The advantage of the "inclined" over "horizontal" fixture is shown for both of the selected side spacings. It can be visualized that some version of the inclined fixture could be placed over the cargo bay (forward of the tail section).

The use of the multipoint fixtures which have the capability of translating the platform after partial assembly would not limit the number of panels that could be serviced. Here the packaging requirements of the fixture system and the platform structure components would become the limiting factors.

Table B-2. Multiple Point Assembly Fixture Installation Comparisons

	NUMBER PANELS SERVICED BY RMS	
	HORIZONTAL FIXTURE	INCLINED (60°) FIXTURE
FAR SIDE (OPPOSITE RMS BASE) INSTALL		
CLOSE IN (2')	3	6
EXTENDED (10')	3	4
NEAR SIDE INSTALL		
CLOSE IN (2')	8	8
EXTENDED (10')	6	8

REFERENCES FOR APPENDIX B

A. Space Shuttle System Payload Accommodations, Level II Program Definition and Requirements, JSC 07700, Volume XIV, Rev. F, September 22, 1978 (including October 5, 1979 revisions).

B. Advanced Technology Program for Large Space Structures, Part 4, Final Report, Rockwell International, Report No. SD 77-AP-0123 (NASA CR-145315), November 1977 (Revised March 1978).

C. Erectable Space Platform for Space Sciences and Applications, Final Report, SSD 79-0074 (NASA CR-159091), prepared under Contract NAS1-15322 by Rockwell International for NASA-Langley Research Center; June 14, 1979.

APPENDIX C

TIMELINE COMPARISONS

APPENDIX C

TIMELINE COMPARISONS

C.1 INTRODUCTION

It is of interest to provide a general concept of operational differences among the four space platforms being analyzed in detail in the current study. This appendix summarizes the assumptions and methodology used in providing the assembly timeline rough order of magnitude (ROM) estimates.

The platform construction activity analyzed was limited to the orbiter-based assembly of the structural components and the installation of a set of utility distribution components. The following sections provide (1) a comparison of platform characteristics that could impact the assembly activities, (2) a summary of construction capability assumed applicable for all the assembly activities, and (3) a summary of the timeline development for the four platforms.

C.2 PLATFORM CHARACTERISTICS

Sketches of the four platforms being analyzed are shown in Figure C-1. Various factors which will impact the construction timeline estimates are shown in Table C-1. It will be noted that the platforms vary widely in size so that great differences in the timelines may be expected. Because of the size and design detail variations, it will not be possible to determine a "best" assembly and design approach from the present limited analyses. The objective of the comparisons is only to establish a ROM of assembly operation times for the different classes of assembly fixtures being analyzed. Details of applicable timeline assumptions are shown in the next section.

C.3 TIMELINE DEVELOPMENT

The general ground rules and assumptions used in the timeline comparison analyses are shown in Table C-2. For comparison purposes, similar time rates will be used for construction activities (e.g., RMS translation of a strut) for all platforms. The platform size variations make it evident that potential applications would come much later for Platform D (see Figure C-1) than for the smaller platforms, so experience and learning would have taken place. Corrections for such refinements in analysis are not possible in the present study.

The following sections will summarize timeline estimates (or references) for each of the four platforms being studied. A summary comparison chart also will be presented.

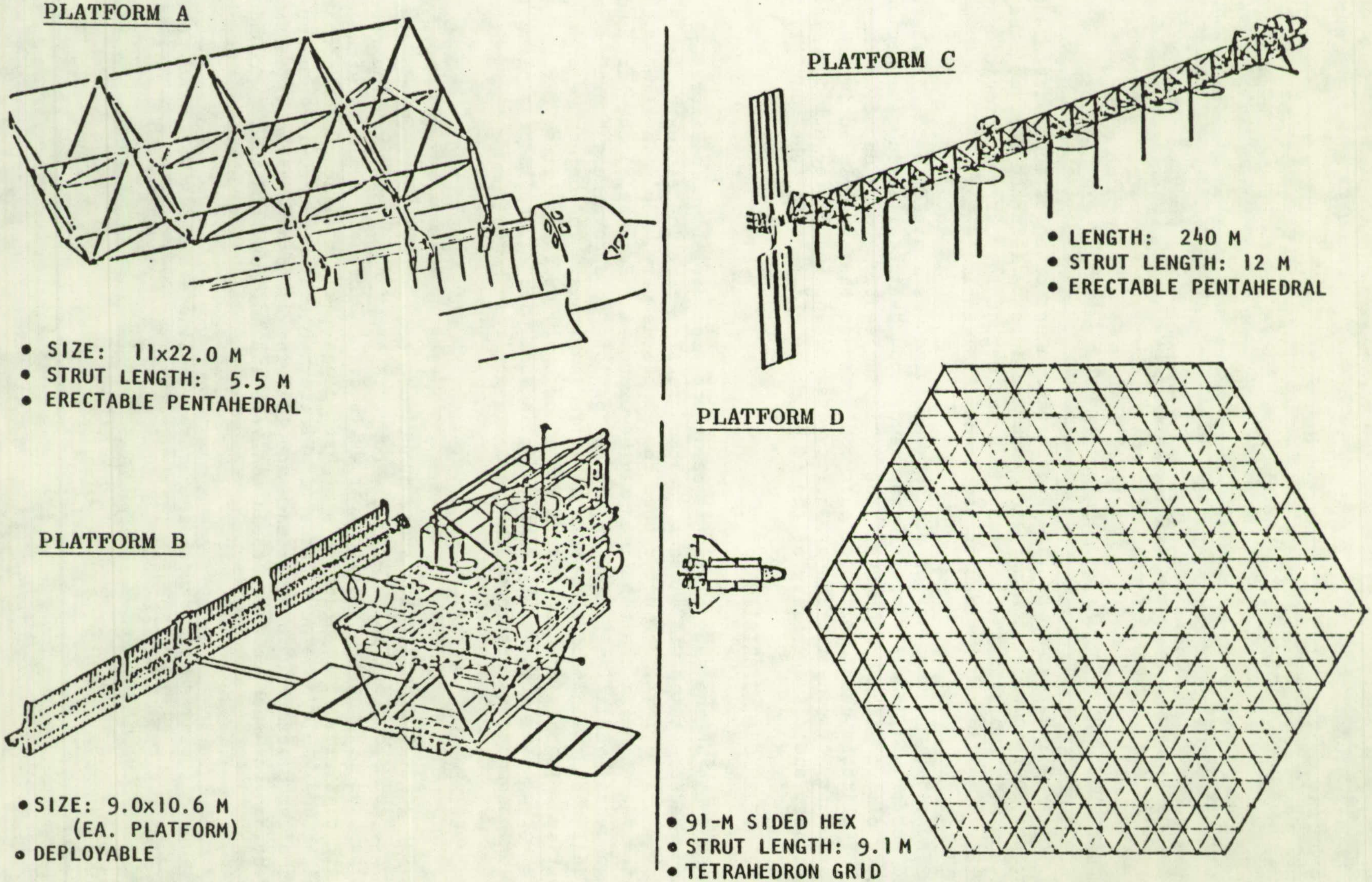


Figure C-1. Platform Configurations

Table C-1. Structure Assembly Comparison Factors

FACTOR	PLATFORM A ERECTABLE SCIENCE & APPLIC. PLATFORM	PLATFORM B DEPLOYABLE SCIENCE & APPLIC. PLATFORM	PLATFORM C ERECTABLE ADV. TECHNOLOGY PLATF. (LINEAR)	PLATFORM D ERECTABLE TETRAHEDRAL AREA PLATF.
PLATFORM DIMENSIONS (METERS)	11×22	TWO 9.3×11.0	12×240	91 M HEX SIDES (~158×182)
PLATFORM PLAN AREA	242 M^2	205 M^2	2880 M^2	21,734 M^2
NO. OF COMPONENTS IN STRUCTURE ASSEMBLY	17 KITS 18 STRUTS	TWO DEPLOYABLE ASSEMBLIES	62 UNIONS 160 STRUTS	300 KITS 331 UNIONS 870 STRUTS
NO. P/L PALLET POSITIONS (FACING SAME DIRECTION)	15 AT 5.5-M CENTERS	12 AT 5.5-M CENTERS (4 OPPOSITE)	N/A	80 AT 18.3-M CENTERS (331 AT 9.1-M CENTERS)
PLATFORM "CELL" FORMAT	PENTAHEDRAL 5.5-M STRUTS	SQUARE FACE WEDGE ~4.9 & 11.0 M DEPLOYED STRUTS	PENTAHEDRAL 12-M STRUTS	TETRAHEDRAL 9.1-M STRUTS
PLATFORM ASSEMBLY FIXTURES & TOOLS	RMS ASSEMBLY FIXTURE	RMS, BERTHING ADAPTER	RMS, ASSEMBLY FIXTURE, STRUT ASSY DEVICE	RMS, ASSY FIXTURE, STRUT ASSY DEVICE, KIT ASSY FIXTURE
NO. "CELLS" PER PLATFORM	8	12	20	300
PLATFORM CELL TRANSLATION DURING ASSEMBLY	RMS	BERTHING ADAPTER	ASSY FIXTURE POWER DRIVE	ASSY FIXTURE POWER DRIVE

Table C-2. Platform Timeline Ground Rules and Assumptions

1. Orbiter-based assembly
2. Automated assembly to extent feasible, EVA for contingency, possible EVA for assembly preparation (after assembly orbit established), and for orbiter return to earth (after assembly operations complete).
3. Use *Construction Standards and Practices* guidelines to extent feasible for all assembly methods.
4. Divide platform system construction operations into two categories:
   a. Structure assembly (including subsystems)
   b. Utility line installation (to payload interface)
5. For comparative analyses, use similar time estimates for similar activities in all four platforms. Grasp, release, install, etc., functions use same time allowances. Translation functions use times proportional to estimated distances.

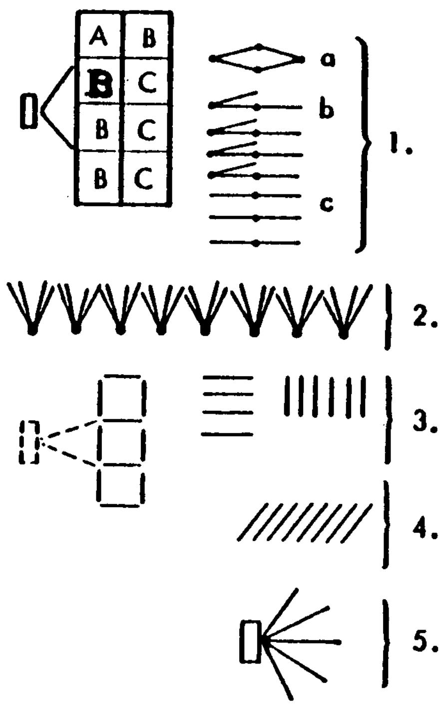
C.3.1 Platform A, Erectable Class I

The general concept of Platform A is illustrated in the upper left sketch of Figure C-1.* Further details of the development of this platform concept are given in Reference C-1. Figure C-2 lists the preassembled kits and individual pieces assumed for the assembly of the platform structure. The installation of utility distribution segments for the platform is analyzed separately, although a present concept (Task 10.0 report, SSD 80-0017) for a typical utility distribution installation calls for integration of the utility duct assembly and the structure assembly for a Platform A-type unit.

The construction fixture assumed is a platform deployed on the left side of the orbiter bay, the same side as the RMS. Further analysis during the study resulted in the recommendation of fixture placement on the side opposite the RMS base. (See Section 4.2.3.) The platform would provide four union attachments in a square pattern to hold the basic tetrahedral cell during construction. Rail extensions in the X and Y directions will provide support during platform translation. The platform rails separating the union retention devices are slotted so as to retain the platform through mating unions at three points during platform translation.

Table C-3 provides a summary of time allocations used in the assembly of the first two bays of Platform A. The average time for all eight bays is estimated at approximately 54 minutes, or a total of 486 minutes (7.2 hours) for the complete structural assembly. Table C-4 provides a sample of a next level of breakdown of the time estimation procedure. The time for the addition of the utility module kit plus the installation of the 10 utility duct segments and 5 utility junction boxes was estimated at 434 minutes (7.23 hours). The resultant total time estimate for Platform A activation is then 18.43 hours, including a three-hour allowance for subsystems checkout. The average platform translation time allowance for the erectable platforms A, C, and D is shown in Figure C-3.

*NASA CR-159091



1.	THREE TYPES TOP SURFACE KITS	8 KITS
	a. 4 STRUT, 4 UNION KIT (1) b. 3 STRUT, 2 UNION KIT (4) c. 2 STRUT, 1 UNION KIT (3)	
2.	EIGHT INTERSURFACE KITS (8)	8 KITS
3.	TEN LOWER SURFACE CONNECTING STRUTS	10 PIECES
4.	EIGHT TOP SURFACE DIAGONAL STRUTS	8 PIECES
5.	ONE UTILITY MODULE TO P/F STRUCTURAL ADAPTER KIT	1 KIT

Figure C-2. Platform A Components for Assembly

Table C-3.
Platform A—Erectable Platform Timeline Summary

Item	Unit Times (min)		Block Completion Times (min)
1. RMS deployment	30	Ready Construction Aids	60
2. Assembly fixture deployment	30		
3. Kit la installation	15	Bay 1	51
4. Diagonal strut 1	7		
5. Kit 2 installation (No. 1)	13		
6. Intercell strut (No. 1)	6		
7. Translate platform	10		
8. Kit lb installation (No. 1)	15	Bay 2	53
9. Diagonal strut No. 2	7		
10. Kit 2 installation (No. 2)	13		
11. Connect intercell strut	2		
12. Install intercell srut 2	6		
13. Translate platform	10		

Table C-4. Assembly Time Estimates
Erectable 2x4 Platform (18' Struts)

	Δt	Time (min)	Σ
1. Check out and deploy RMS		30	30
2. Check out and deploy assembly fixture		30	60
3. Install Cell 1 Kit 1(a) on assy fixture		15	75
(a) RMS move to P/L storage (30')	0.83		
(b) Release of kit flight restraints	1.00		
(c) Release grip Kit 1a	1.00		
(d) Move kit to assy fixture (40'), Union 1	1.00		
(e) Install corner union in fixture	2.00		
(f) Move RMS to second union (~20')	0.67		
(g) RMS grip union	1.00		
(h) Move union (~13') est.	0.60		
(i) Install union in fixt. retention	1.00		
(j) Move RMS approx 20' to 3rd union	0.67		
(k) RMS grip union	1.00		
(l) Install in fixture retention	1.00		
(m) Move RMS approx 20' to 4th union	0.67		
(n) RMS grip union	1.00		
(o) Install in fixture retention	1.00		
(p) Return RMS to neutral (10')	0.47		
Total	14.91	(Use 15 min.)	
4. Install diagonal strut in Cell 1		70	82
(a) RMS move to P/L storage (10')	0.47		
(b) Release diagonal strut flight restraint	1.00		
(c) Grip diagonal strut	1.00		
(d) Move strut to Union 4 (20')	0.67		
(e) Install strut end in union	1.00		
(f) Move RMS to opposite end (25')	0.75		
(g) Install strut end in Union 2	1.00		
(h) Return RMS to neutral (30')	0.85		
Total	6.72	(Use 7 min.)	

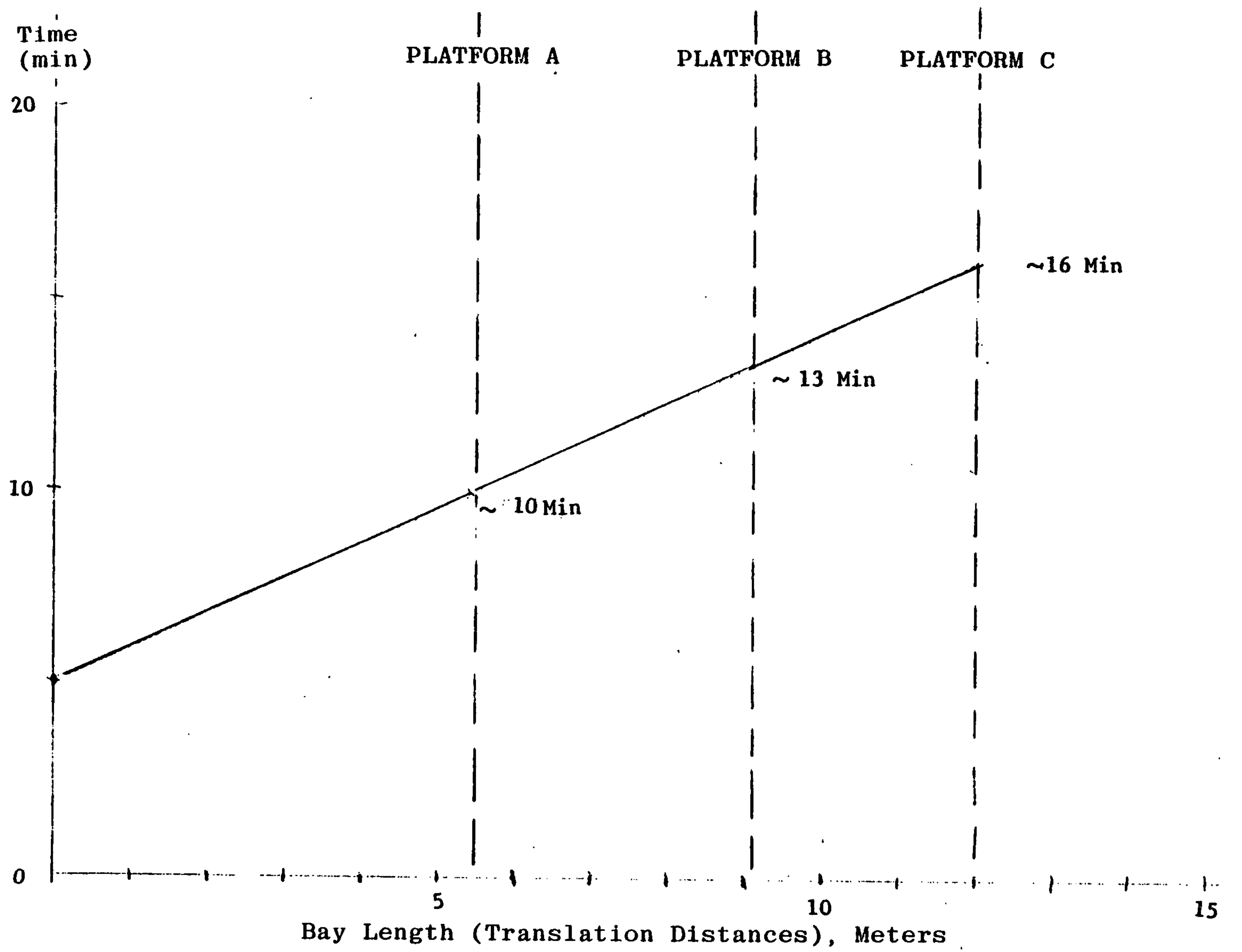
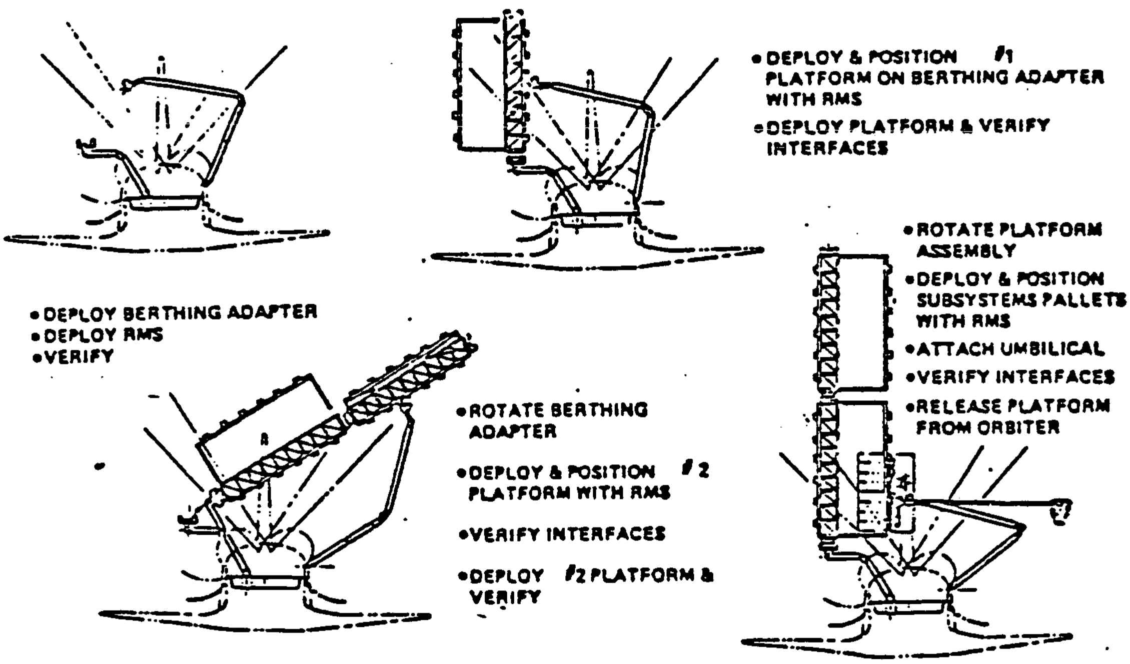


Figure C-3. Average Translation Time Assumptions—Platforms A, C, and D

Further details of basic RMS operations time duration assumptions and translation time allowances are shown in References C-2 and C-3.

C.3.2 Platform B, Deployable Class I

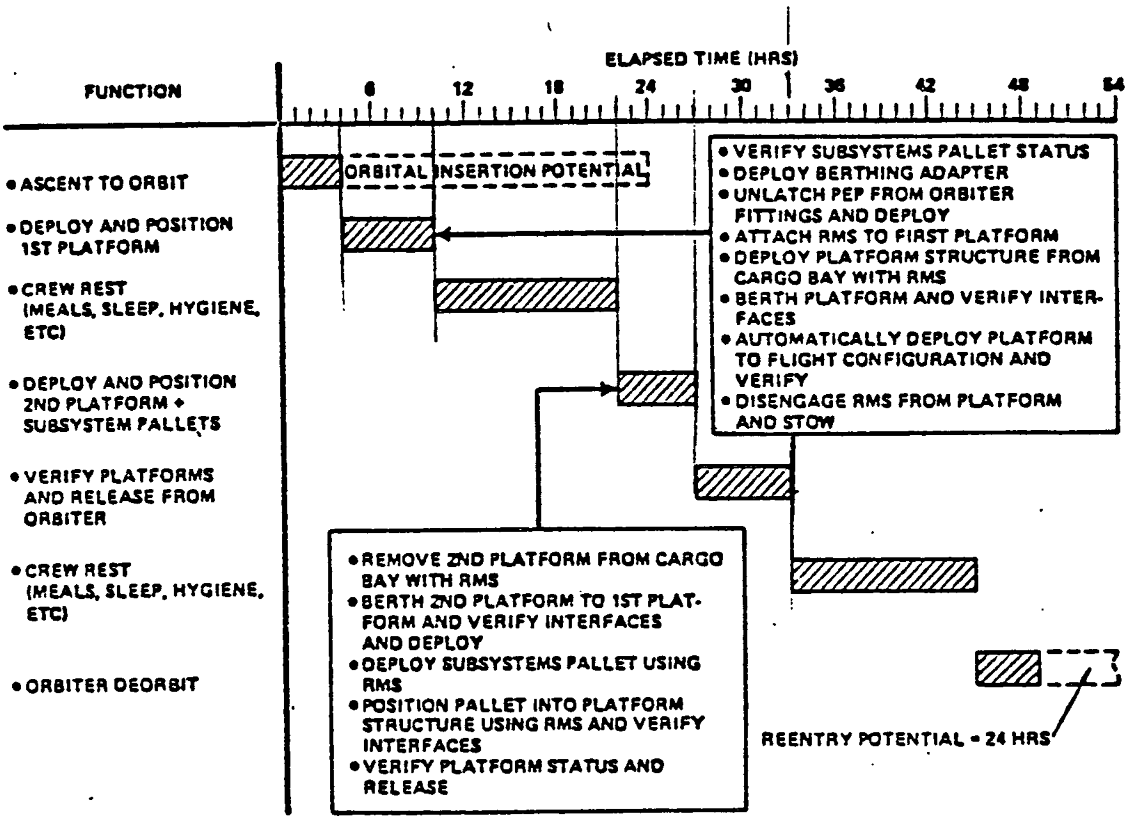
The Platform B concept is illustrated in the lower-left sketch of Figure C-1. This is a deployable-type structure design with the major utility distribution system integrated with the structure prior to launch. The deployment concept includes a berthing adapter to hold the packaged structure (moved from the orbiter bay by the RMS) during the deployment operation. The activation sequence (from Reference C-4, p. 65) is summarized in Figure C-4.



(from Reference C-4, p.67)

Figure C-4. Platform B, Deployable Platform Activation Sequence

Reference C-4, p.67, also provides a timeline summary indicating a total of approximately 17 hours of workting time for the deployment and positioning of the two platform units, installation of the utility subsystem pallets, and the activation and verification of the platform subsystems. The referenced timeline summary is shown as Figure C-5. It will be noted that this timeline allows six hours for platform "verification" versus the three-hour allowance shown for the previous erectable platform example.



(from Reference C-4, p.67)

Figure C-5. Platform B, Deployable Platform On-Orbit Assembly Timeline

C.3.3 Platform C, Linear Erectable Class II

The linear erectable Class II structure concept, selected to represent a larger-type space platform, is depicted in the upper-right sketch of Figure C-1. Another view illustrating a construction fixture concept for the 20-bay pentahedral cell structure is shown in Figure C-6. Further details of this platform concept and construction operations are given in Reference C-5.

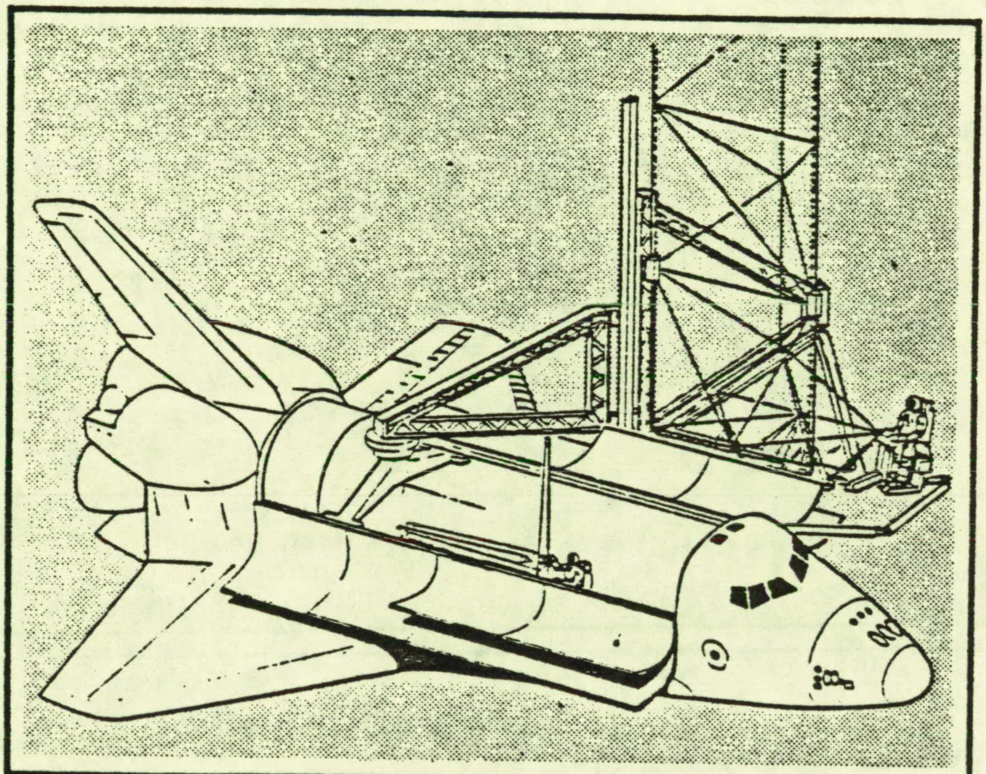


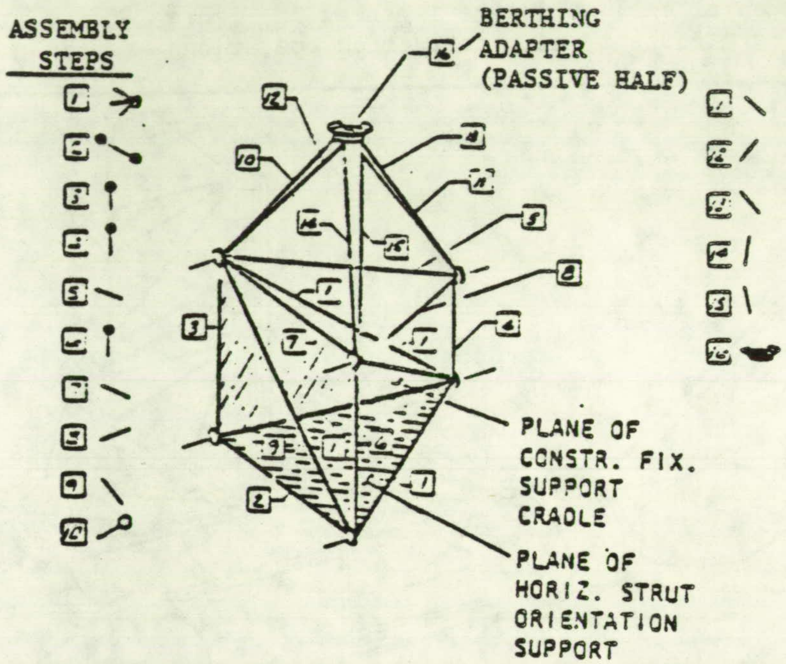
Figure C-6. Construction Fixture for Linear Platform

For the current timeline estimate, the automated (RMS) assembly operations are assumed with EVA operations as backup. A vertical translation of the platform relative to the orbiter was selected. The assembly fixture allows translation of the platform to provide completion of the structure first, then translation back through the fixture during utility distribution line segment installation and, finally, a final translation through the fixture during subsystem (e.g., RCS structure and components) and payload (e.g., antennas) installation. The present timeline analysis will consider only the structure and utility distribution segments of the operations.

Platform C structure assembly and time estimates were analyzed in the Rockwell study (Reference C-5, Section 02-0501.1-04.2). A summary of the results is shown in Figure C-7. The 137 minutes per bay average results in a total of 137×20 = 2740 minutes (45.67 hours) for the total structural assembly.

FUNCTION· ITEM	JOIN STRUTS, UNIONS, BERTHING PORTS	CODE	02	05 01.1	04.2
METHOD	RMS/STRUT CLUSTER	PAGE	3 of 6		
SUBJECT	OPERATIONS				

STRUCTURE ASSEMBLY SEQUENCE



Manpower

- One RMS Operator at AFD

Activity Time

- Strut and union removal from cargo bay	5 min.
- Strut/union assembly at strut fixture	3 min.
- Transport strut to platform	2 min.
- Join strut to platform	10 min.
TOTAL PER STRUT (AVERAGE)	20 min.
- Repeat operations for next four struts to complete base and apex tie struts	80 min.
- Remove strut cluster from cargo bay	2 min.
- Cluster/union assembly of strut fixture	12 min.
- Cluster transport to platform	3 min.
- Strut joining	20 min.
TOTAL PER BAY	137 min.

Other

- Major joining operations will be performed in light portion of orbit to permit visibility for moving the long struts around.

Figure C-7. Platform C Structure Assembly Timeline

The same reference (Section 02-0601.1-04.1) provides an estimate of 140 minutes for an RCS assembly including structural and electrical connections. The present timeline analysis will assume the installation of two such assemblies. The time estimates made for the assembly of electrical lines and junction boxes to the Platform C structure is summarized in Table C-5. The total time estimate for Platform C activation is then approximated at 78.32 hours of RMS and construction fixture related operations.

Table C-5. Platform C Utility Line Installation Time Estimate

Assumptions: Utility line segments installed in 12-m (40-ft) lengths, one piece, rigid enough to be handled by RMS.

Number Segments: 20 along longitudinal beam plus 20 along crossbeams, four attachment points per segment.

Segment-to-Segment Connections: 19 between longitudinal segments, and 20 between crossbeam segments and longitudinal segment assembly.

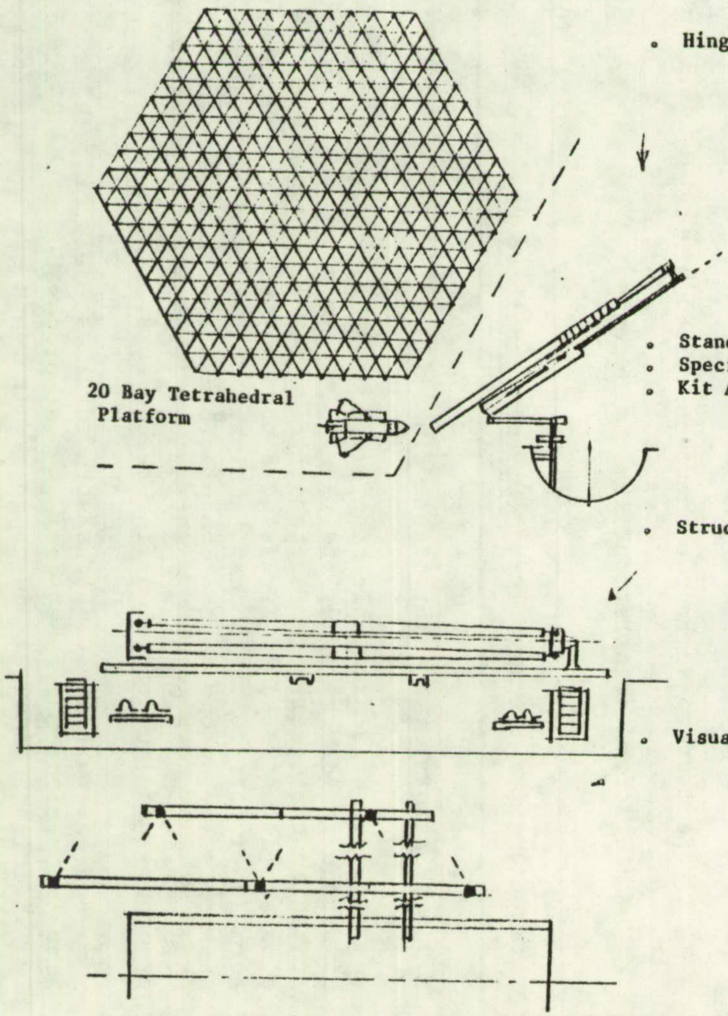
Time Estimate:	Minutes
1. Segment removal from cargo bay and translation to assembly position—40×5 minutes =	200
2. Segment attachment to structure, 40×4×2 minutes =	320
3. Segment-to-segment connections, 39×5 minutes =	195
4. Platform translation, 19×16 minutes =	304
Total	1019

1019 min. or 16.98 hr

C.3.4 Platform D, Area Erectable Class II

A large area erectable platform concept was selected for the fourth type of structure for the study analyses. The hexagonal shaped platform is illustrated on the lower-right sketch of Figure C-1. Further details of the concept also are illustrated in Figures C-8 through C-12. This tetrahedral area platform is similar to the concept analyzed in depth in Reference C-2. The numbers of struts and unions in the two platforms are the same. The differences are in the reduced length of struts (9.1 m vs. 16.5 m) and differences in assembly procedures and construction fixture concepts.

For the current study the structural assembly fixture is basically the same (with minor modifications) as that proposed for the Platform A assembly. Two additional fixtures and their requirements are summarized in Figure C-8. These are an automated hinged strut assembly fixture and a kit assembly fixture as illustrated in Figure C-9.



FIXTURE REQUIREMENTS

- Hinged Strut Assembly Fixture
  - Electrical power, Orbiter to Fixture
  - Control circuits, Orbiter to Fixture
  - Hold stack of nested hinged struts
  - Extract hinged strut from stack
  - Provide controlled unfolding of strut
  - Release completed strut to RMS for translation to "kit" assy. fixture
  - Rotate fixture from Orbiter storage to operating position.
  - Release Strut assembly fixture from Orbiter for on-orbit storage.
- Standard RMS
- Special "Cherry Picker" Installation
- Kit Assembly Fixture
  - Union mount locations for kit ass'y
  - Union canisters, fore and aft locations
  - EVA foot restraints at ass'y locations
  - Fixture attachment to Structure Assy Fixture
- Structure Assembly Fixture
  - Electric Power, Control interface with Orbiter
  - Telescoping union support rails
  - Telescoping & hinged extension rails
  - Structure fore/aft translation mechanism
  - Fixture orbiter disconnect interface for on-orbit storage
  - EVA foot restraints
  - Storage locations for other assembly aids
- Visual Aids

Figure C-8. Tetrahedral (Class II) Area Platform Requirements Summary

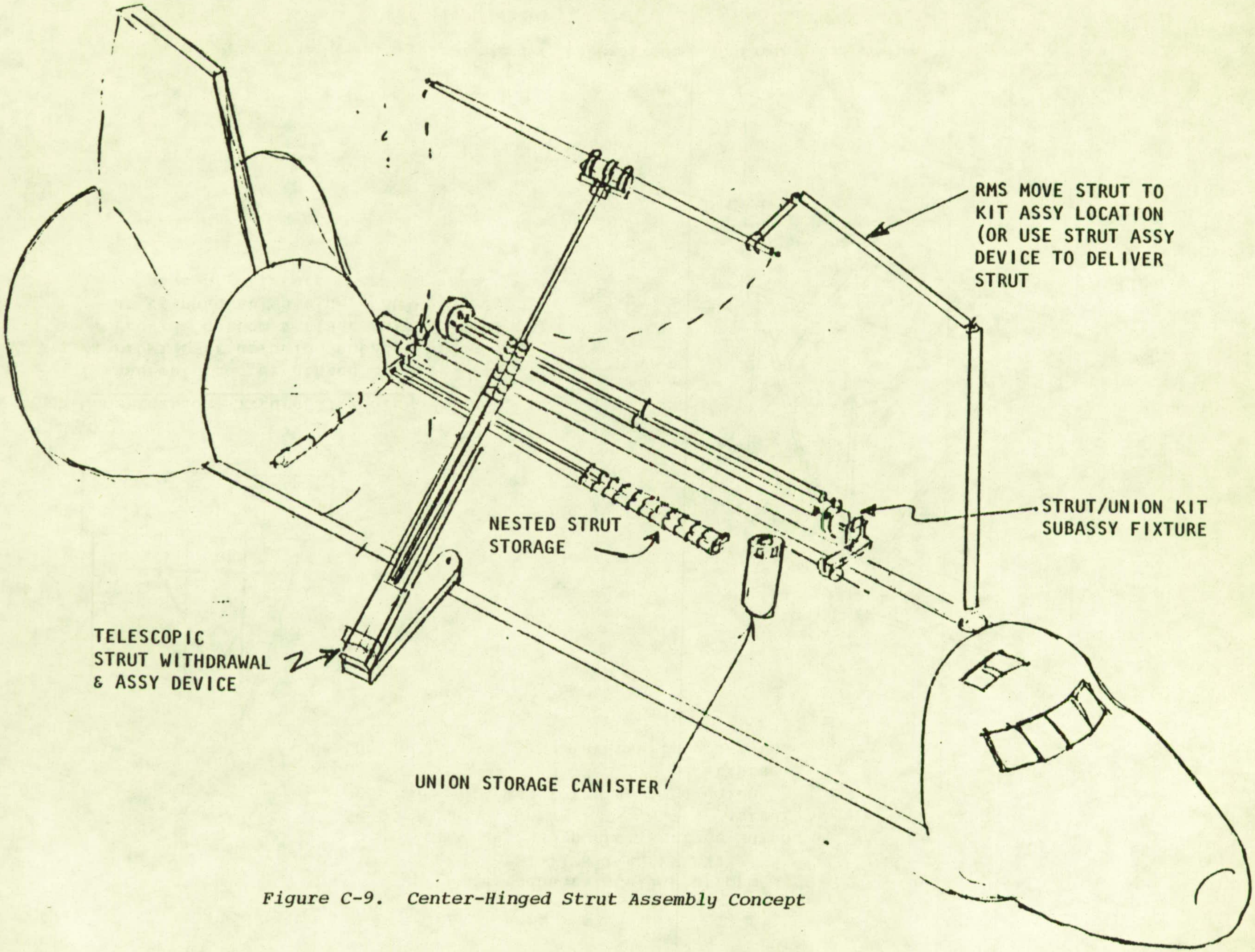
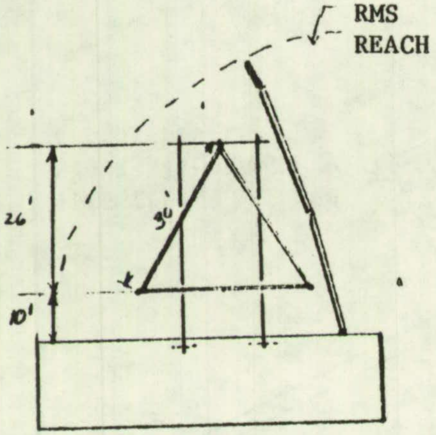


Figure C-9. Center-Hinged Strut Assembly Concept

Tetradhedral Cell Platform
STATION 1 ASSEMBLY:
3 Bottom surface unions
4 " " struts
1 Top surface union
3 " " struts
3 Intersurface struts



Construction Fixture(s) Reqts

1. Assemble center-hinged struts
2. Provide strut/union subassemblies
3. Provide bottom surface union clamps (3) at triangular spacing, ~ 30' centers
4. On assembly fixture

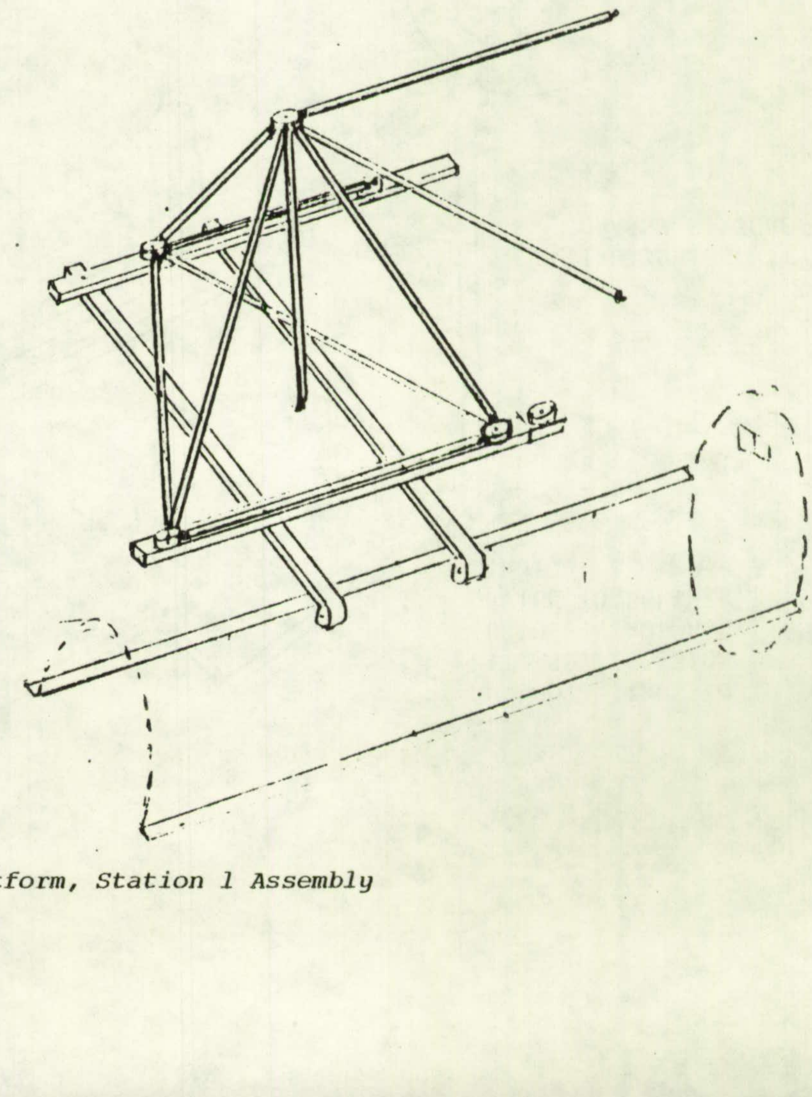
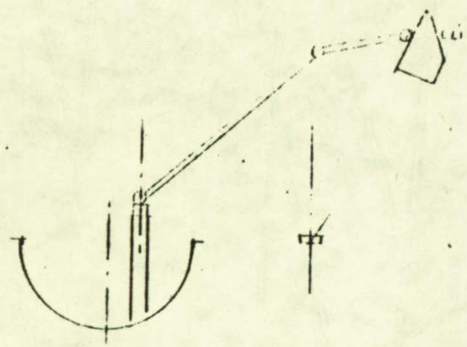


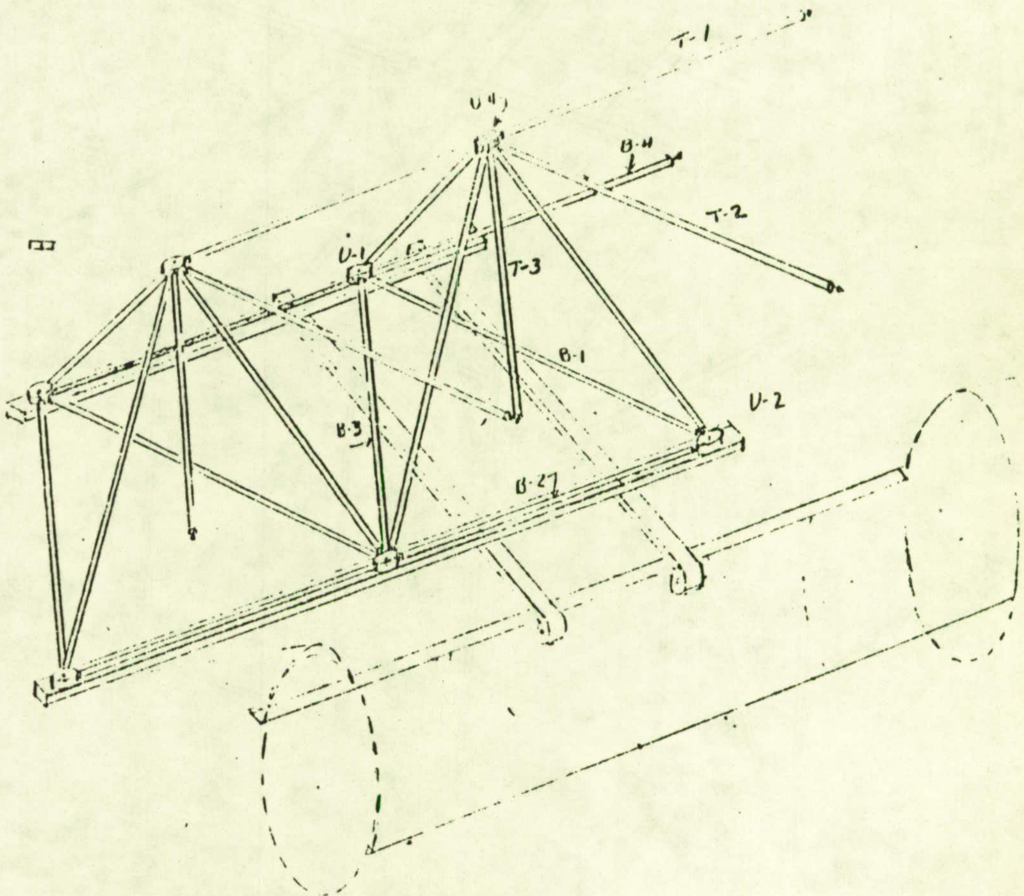
Figure C-10. Tetrahedral Cell Platform, Station 1 Assembly

TETRAHEDRAL CELL PLATFORM

STATION 2 ASSEMBLY:
- 2 Bottom surface unions
- 4 " " struts
- 1 Top surface union
- 3 " " struts
- 3 Intersurface struts



Cherry-picker Mechanism



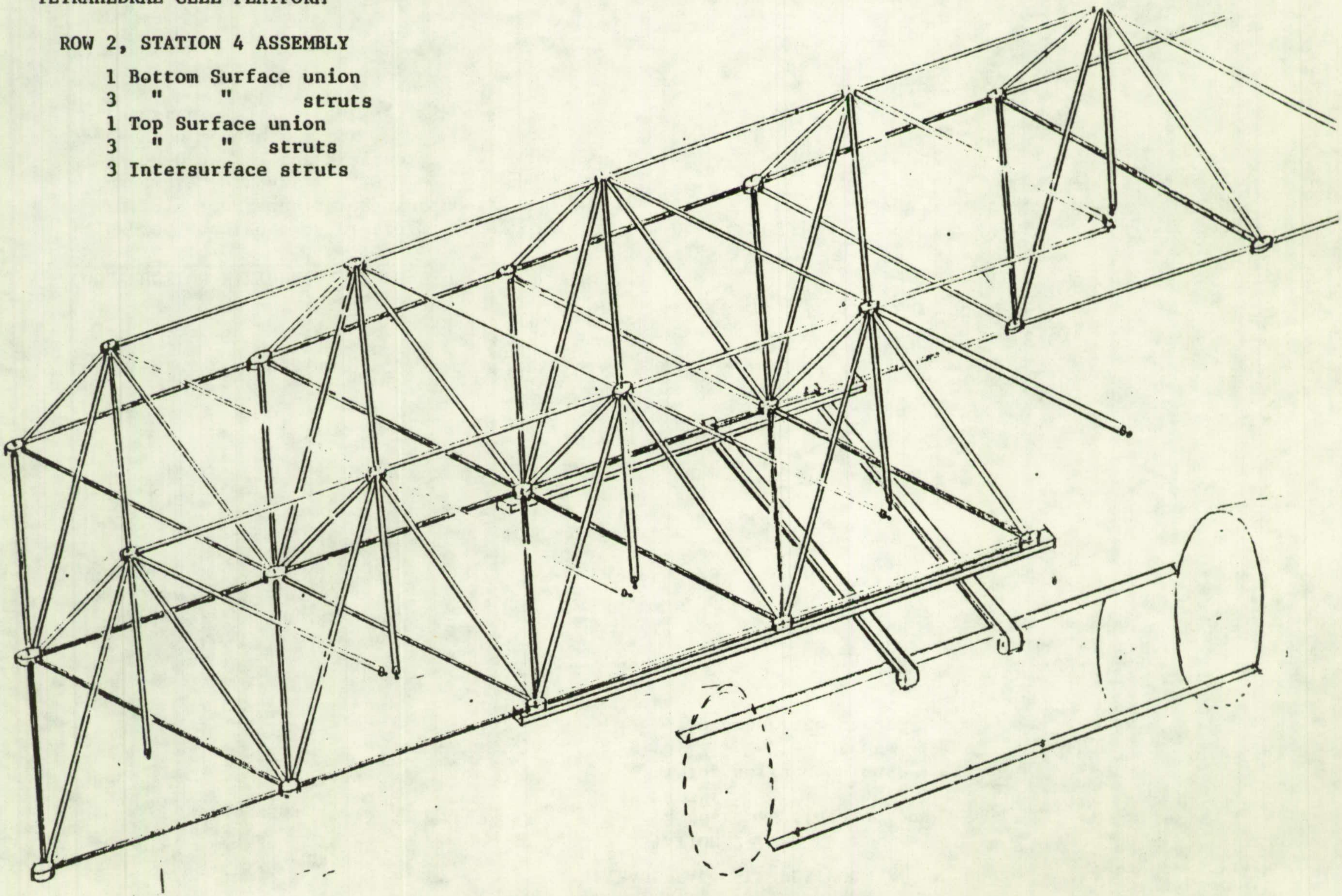
CONSTRUCTION FIXTURE(s) REQTS

1. Expand construction platform rails while translating Station 1. assembly to rear.
2.-4. Same as 1-3 for Station 1.
5. Provide mechanisms for translating Bay 1 rearward

TETRAHEDRAL CELL PLATFORM

ROW 2, STATION 4 ASSEMBLY

1 Bottom Surface union
3 " " struts
1 Top Surface union
3 " " struts
3 Intersurface struts



The number of struts in the Platform D design is equal to 2670, and the number of unions is 631. The currently proposed assembly procedure is to assemble three struts and a union into a tripod kit (intersurface struts), and two struts and a union into a "bottom" surface kit. The number of struts and unions to be assembled at a particular assembly station will vary with the location within the platform. Figures C-10, -11, and -12 illustrate some of these variations. Differences are due to the edge effects and 57 of the 300 bays to be assembled will encounter edge conditions. The number of kits and separately installed struts and unions are shown in Table C-6.

Table C-6. Platform D Assembly Components

Item	Number Kits	Number Struts	Number Unions
Tripod kits	300	900	300
Bottom kits	300	600	300
Separate struts	-	1170	-
Separate unions	-	-	31
Total	600	2670	631

Total structural assembly items = 600 + 1170 + 31 = 1801

To establish a total platform assembly timeline, an analysis of a "representative" cell or bay was made. The Row 2, Station 4 illustration, shown in Figure C-12, was selected. This assembly requires nine struts and two unions, or the two kits plus four separately installed struts. Three-hundred representative bays would then account for the assembly of 2700 struts (vs. 2670 actual) and 600 unions (vs. 631 actual). The totals of both assembly activities appear about right using this type of summary.

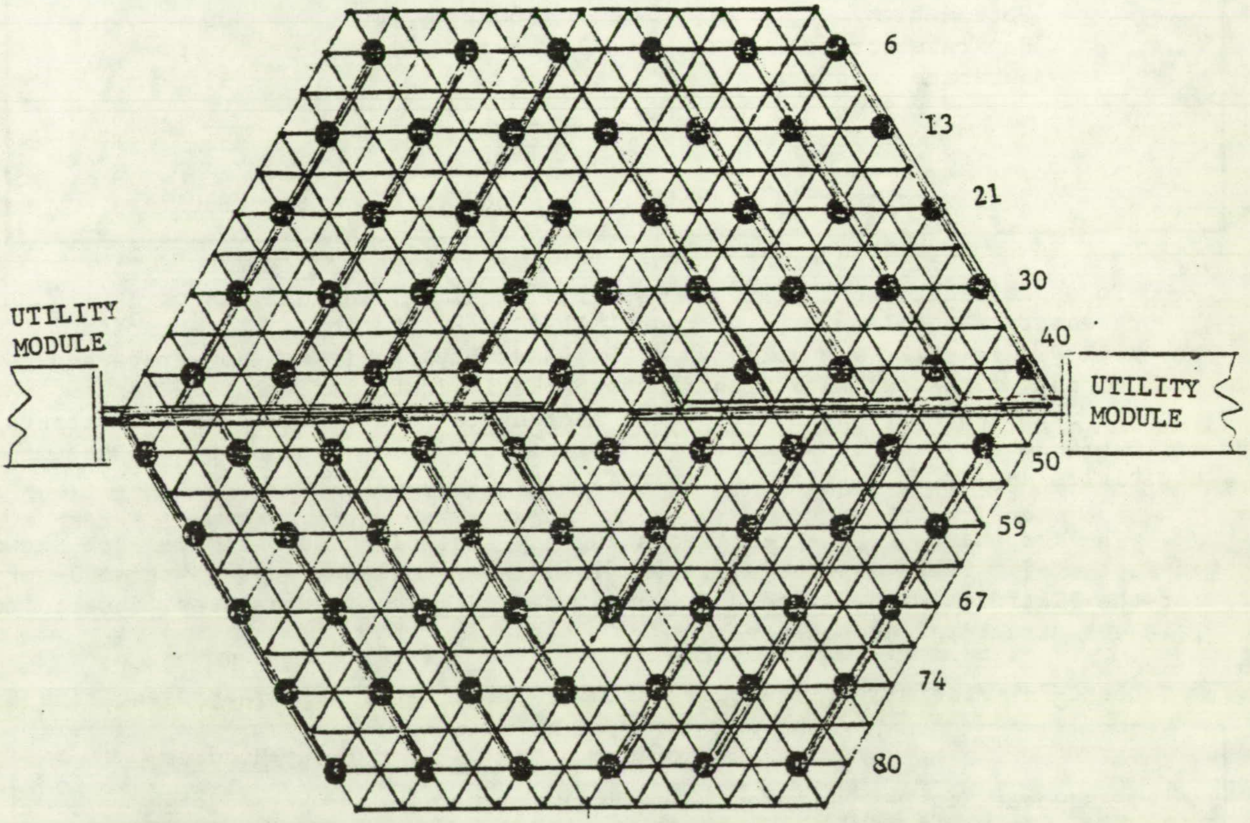
The components of the representative bay assembly time estimates are shown in Table C-7. These estimates are obtained in a similar manner to those described for the Platform A and Platform C, where the RMS grasps, translates, inserts, and releases structural components.

Table C-7. Platform D Structure Assembly Timeline Summary (Representative Bay)

	Minutes
1. Assemble Kit D-1 (1 union, 2 struts)	9
2. Install Kit D-1 on assembly fixture	8
3. Assemble Kit D-2 (1 union, 3 struts)	12
4. Install Kit D-2 on platform	13
5. Install bottom surface strut	7
6. Install 3 top surface struts plus 3 more strut-to-union connections	17
7. Translate platform to next assembly location	13
8. Allowance for strut assembly fixture operations	4
Total	83

The estimated total structural assembly time per representative tetrahedral bay is then 83 minutes. For the total platform (structure only), this estimate would be 83×300 = 24,900 minutes, or 415 hours, or 17.29 days of continuous assembly activity.

For the timeline comparison, an arbitrary set of 80 payload positions on the platform was selected for use in establishing time estimates for the utility line installation. Figure C-13 illustrates the selected pattern and the designation of 174 utility line segments to be installed by attachment to the platform during the construction operations. The individual segments are assumed to be sufficiently rigid to allow handling (from one end) by the RMS, and to require two attachments to the structure and one segment-to-segment electrical/data connection. The time allocations for the Platform D utility distribution installation are summarized in Table C-8.



ASSUMPTIONS:

80 PAYLOAD POSITIONS
2 UTILITY SOURCES
9.1-M (30-FT) LONG UTILITY SEGMENTS TO BE JOINED IN PATTERN SHOWN.
TOTAL NUMBER OF SEGMENTS = 174

Figure C-13. Platform D Utility Distribution

Table C-8. Utility Distribution Installation Time Summary—Platform D

	Minutes
1. Procure and move segment to platform	5.00
2. Attach segment to platform	5.00
3. Complete segment-to-segment connector attachment and continuity checkout	6.00
Total	16.00
Time allowance for 174 segment installations = 174×16 = 2874 min. or 46.4 hr	

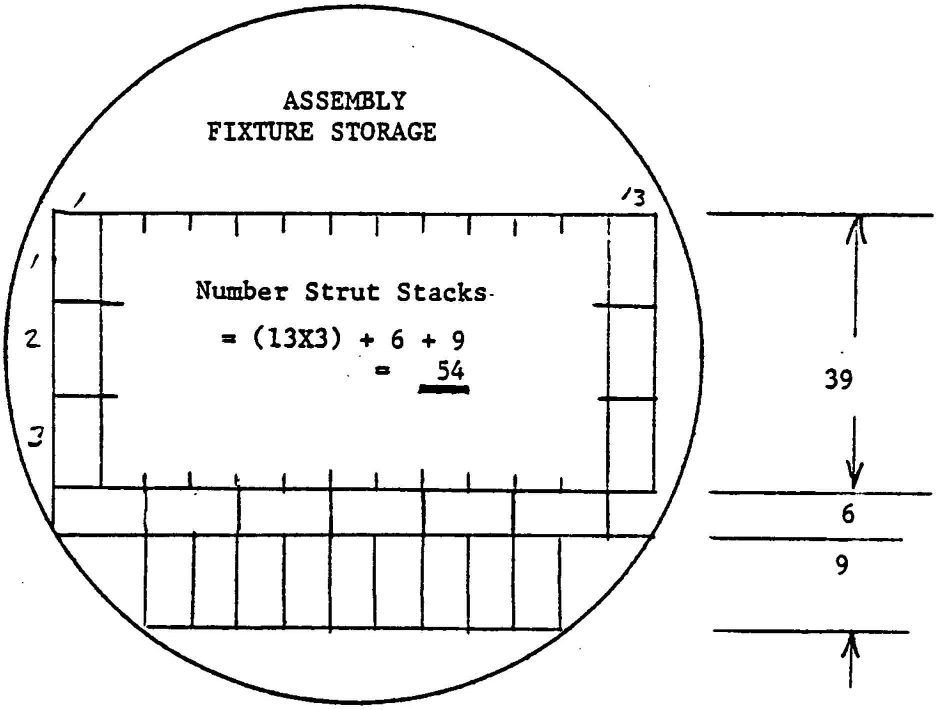
For a platform as large as the assumed Platform D, the packaging of the structural and utility distribution components into the orbiter payload bay must be considered. For this study, the struts were considered to be double-tapered center-hinged struts to allow nested packaging. A 0.2-m center diameter of the strut was assumed. For packaging within the orbiter bay a cross-section requirement of 0.3×0.6 m (1×2 ft) was assumed to allow for flight restraints and release mechanisms. The number of strut stacks that would fit into the orbiter bay cross-section is illustrated in Figure C-14.

Also shown on the figure are the assumptions made for the number of struts per stack (28) and the total struts that could be carried per flight with the stated assumptions. Also shown is the allowance for utility distribution segments and the number of those that could be carried in the same orbiter cross-section.

It is assumed that the other assembly items (e.g., unions, flight restraint items, assembly fixtures) would be stored above the strut/segment stacks (as indicated on the figure) and at one or both ends of the stacks. The resultant number of orbiter flights for the Platform D structure and utility distribution line installation is then 5.

C.4 TIMELINE SUMMARY

The summary of time estimates for the assembly of the four platforms being analyzed in the current study is given in Table C-9. It must again be pointed out that a more thorough timeline analysis must be performed on any specific large structural system platform before more than the ROM estimate can be obtained. A more meaningful estimate can be obtained only after more specific platform designs are determined and more assembly fixture mechanisms and associated operations are tested, both in the laboratory and in space flight.



STRUT PACKAGING CROSS-SECTION

BAY LENGTH FOR STRUT STORAGE = 11.0 m (36 ft)
FOLDED STRUT LENGTH = 4.57 m (15 ft)
NESTED STRUT ADVANCE RATE = 0.23 m (0.75 ft)
NUMBER NESTED STRUTS PER STACK =

$$\frac{11.0 - 4.57}{0.23} = 28$$

TOTAL STRUTS PER ORBITER FLIGHT

$$= 28 \times 54 = 1512 \quad \text{OR} \quad \frac{2670}{1512} = 1.77 \text{ FLIGHTS FOR STRUTS}$$

ASSUME SAME CROSS-SECTION FOR UTILITY SEGMENTS:

$$174 \div 54 = 3.22 \text{ FLIGHTS}$$

TOTAL FLIGHTS = 1.77 + 3.22 = <u>5 FLIGHTS</u>

Figure C-14. Platform D Flight Requirements

Table C-9. *Platform Construction Timeline Comparisons*

ITEM	ACTIVITY	TIME ESTIMATES, MINUTES (HOURS)			
		PLATFORM A	PLATFORM B	PLATFORM C*	PLATFORM D**
1	PREPARE CONSTRUCTION FIXTURES	60 (1.00)	N/A	120 (2.00)	450 (7.50)
2	AVERAGE ASSEMBLY TIME PER BAY	54 (0.90)	N/A	137 (2.28)	83 (1.38)
3	BAYS PER PLATFORM	8	16	20	300
4	TOTAL STRUCTURE ASSEMBLY TIME	432 (7.20)	N/A	2740 (45.67)	2490 (415.0)
5	UTILITY SYSTEM INSTALLATION (INCLUDES ATTACH TO POWER MODULES, ETC.)	434 (7.23)	N/A	1299 (21.65)	2784 (46.40)
6	TOTAL STRUCTURE ASSEMBLY, UTILITY SYSTEM INSTALLATION	926 (15.43)	660 (11.00)	4039 (67.32)	27,684 (461.4)
7	SYSTEMS CHECKOUT	180 (3.00)	360 (6.00)	600 (10.00)	1200 (20.00)
8	TOTAL PLATFORM ACTIVATION TIME	1106 (18.43)	1020 (17.00)	4759 (79.32)	29,334 (488.9)

*ASSUMES 2 ORBITER FLIGHTS

**ASSUMES 5 ORBITER FLIGHTS

APPENDIX C REFERENCES

C-1 Erectable Space Platform for Space Sciences and Applications, Rockwell International, Satellite Systems Division, SSD 79-0074 (NASA CR-159091), June 14, 1979.

C-2 Advanced Technology Laboratory Program for Large Space Structures, Parts 1 and 2, Final Report, SD 76-SA-0210 (NASA CR-145206), May, 1977.

C-3 Space Construction Standards and Practices, Rockwell International, 6 September 1979 (Draft Copy).

C-4 Deployable Orbital Service Platform Conceptual Systems Study, McDonnell Douglas (MDC G7832), March, 1979.

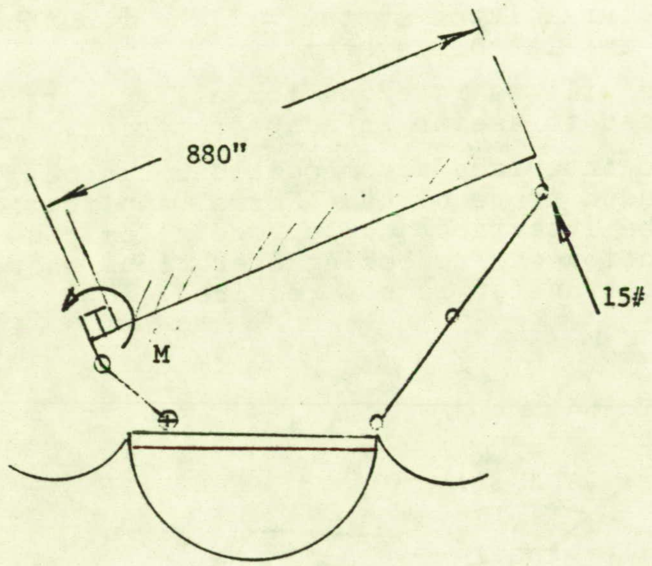
C-5 Space Construction Data Base, Rockwell International (SSD 79-0125), June, 1979.

APPENDIX D

ANALYSES

ASSUMPTIONS: a) CONSTRUCTION IS DONE IN FREE DRIFT MODE

b) LOADS ON FIXTURE (i.e., LATCH LOADS, ARM LOADS etc) ARE INDUCED BY RMS (15# MAX - FULLY EXTENDED)



$M = 880 \times 15 = 13200''^{\#}$

ASSUME MAX LATCH TO BE $500^{\#}$/LATCH

CITCLE DIA OF LATCH THEN $= \frac{13,200}{500} = 26.4$ IN

IF 32 IN DIA IS CHOSEN:

THEN LATCH LOADS $= \frac{13,200}{32} = 412^{\#}$ LATCH

Figure D-1 - Fixture Interface Latch Loads

INTERFACE ADAPTER ARRANGEMENT

ISSUE: PROVIDE INTERFACE ARRANGEMENT AND SIZING

ASSUMPTIONS:

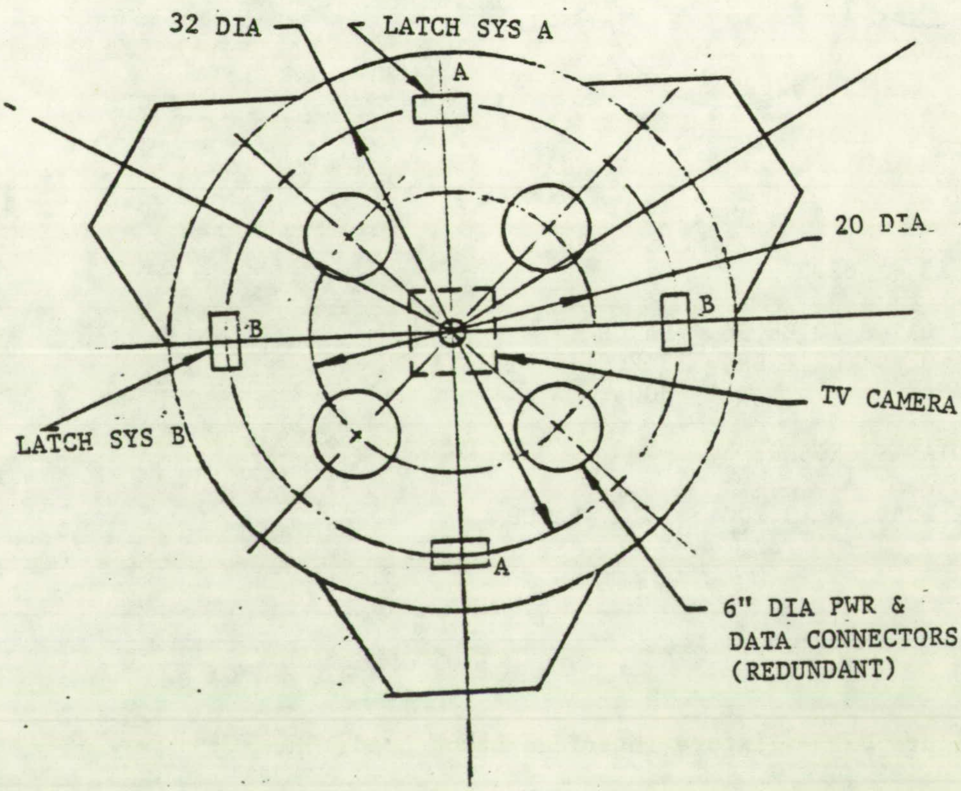
(a) Electrical power and data lines will be internal to fixture with transfer across interface.

(b) Power and data lines will be redundant.

(c) Structural latch system will be redundant with two latches/system.

(d) Space will be reserved for a TV camera mounted to assist in adapter mating.

(e) Fluid interface accommodations can be included if required. Normal applications of the interface adapter occur for construction and redocking operations where fluid transfer is not required.

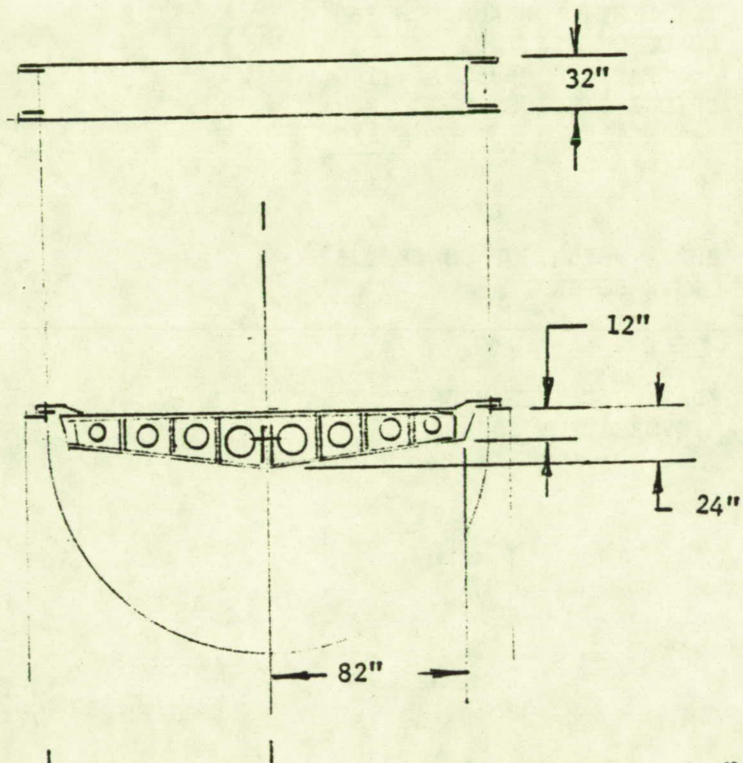


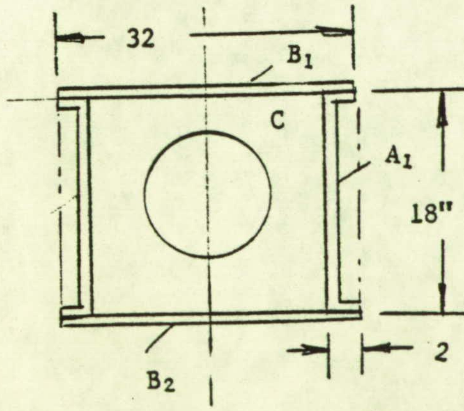
PROBLEM: EVALUATE CONCEPT A AND CONCEPT B FOR WEIGHT COMPARISON

ASSUMPTIONS:

a) Concept A and Concept B fixtures (including stowage provisions) are approximately equal in weight

b) Passive trunnion latches will be used to retain beam





All thickness 3/16"

$$A_1 = \left(\frac{3}{16} \times 17\frac{5}{8}\right) + \frac{3}{16} \times 2\ (2)$$

$$3.313 + .75 = 4.06\ IN^2$$

$$B_1 = \frac{3}{16} \times 32 = 6\ IN^2$$

$$C = (28 \times 18) \times \overset{\text{FOR HOLES}}{\frac{1}{3}} = 168 IN^2$$

NOTE: 7 Gussets ea side will be equiv. to holes removed

CONCEPT WEIGHT COMPARISON

VOLUME = $(A_1 + A_2)$ (164 IN)	= 4.06 (164)	=	666
+ $(B_1 + B_2)$ (164 IN)	= 12 (164)	=	1968
C X 5	= 168 X 5	=	840
			3474 IN^3

USING ALUMINUM MAT'L

WT = 3474 X .10 = 347# + 1070 = 382#

WT of BEAM	= 382#
* WT of TRUNNIONS	= 183
TOTAL WT.	= 565#

TOTAL WT OF BEAMS	= 565#
* LONGERON FITTINGS 4 PASSIVE @ 35#	= 140
* BRIDGE FITTINGS 4 @ 115	= 460
	1165#

DELTA WEIGHT OF CONCEPT B OVER CONCEPT A = 1165#

*DATA OBTAINED FROM ERNO PALLET INFORMATION SOURCE

APPENDIX E

CONSTRUCTION FIXTURE LAYOUTS AND SKETCHES

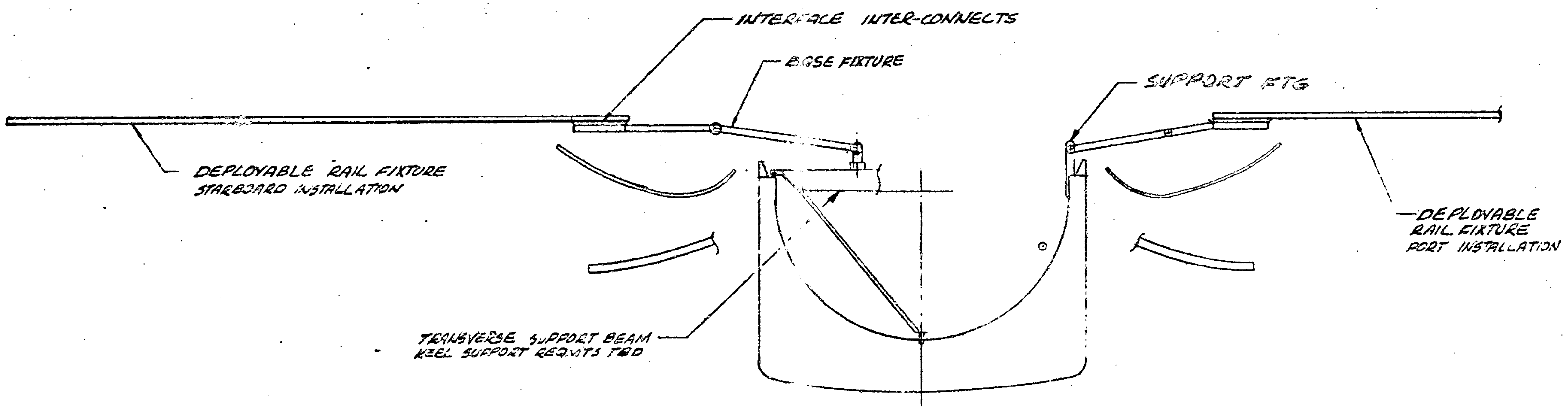
APPENDIX E

INTRODUCTION

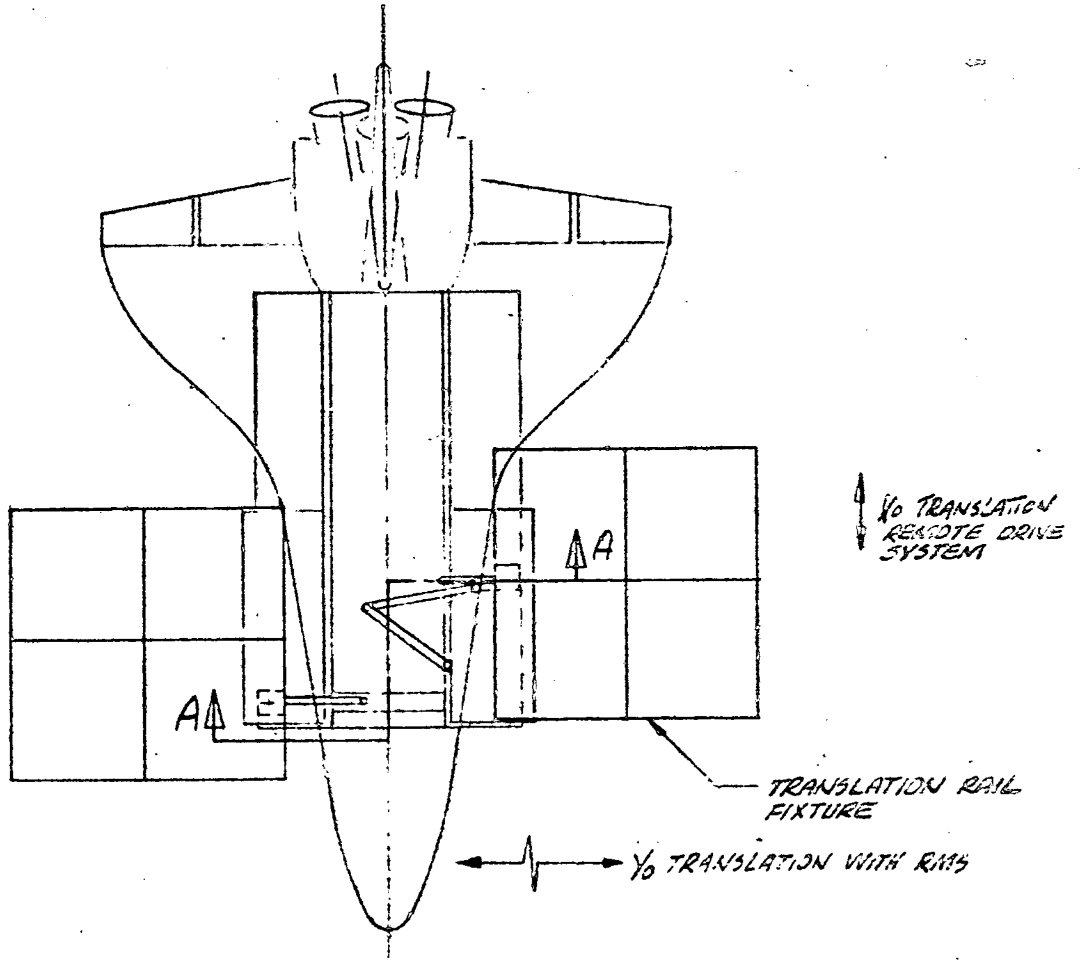
This appendix contains the concept sketches and layouts of a construction fixture prepared during this study. Drawing No. 42537-131, Sheets 1 and 2, represents the final layout of the fixture concepts including Concepts A and B for the base fixture (Segment A) as well as the design of the Segments B and C fixtures. It should be noted that time did not allow for the design of the keel tiedown fitting. Further design study is needed in this area. Sketches A through E represent some early concept thoughts including fixture orientation with respect to the orbiter. Sketches F through H represent preliminary concepts of translating rails for Segment B and C fixtures.


ASSY FIXTURE AREA PLATFORM STARBOARD INSTALLATION SEE DETAIL
SUPPORT STRUCTURE
ORBITER ORIENTATION VIEW
CONCEPT B
SCALE: 1/80
BRIDGE FITTING
CARGO BAY DOOR
DETAIL C
SCALE: 1/4
ASSEMBLY FIXTURE AREA PLATFORM STARBOARD INSTALLATION SEE DETAIL
ORBITER ORIENTATION VIEW
CONCEPT A
SCALE: 1/80
ASSEMBLY FIXTURE LINEAR PLATFORM PORT INSTALLATION SEE DETAIL
40.00 DIA EVA PASSAGEWAY
SUPPORT CRADLE WITH ACTIVE RETENTION LATCH
SECTION B-B
VIEW LOOKING AFT
SCALE: 1/20
FIXTURE INTERFACE
CENTER MOUNTED CAMERA
VIEW M-M
STOWED POSITION AT Xo 630.44
STOWED POSITION AT Xo 880.00
SECTION A-A
VIEW LOOKING AFT
CONCEPT A
SCALE: 1/20
Rockwell International Corporation
Space Division
12214 Lakewood Boulevard • Downey, California 90241
DR BY J. GIMONIAN 1-3-80
CHK BY
APPROVED BY
CONSTRUCTION FIXTURE - LARGE SPACE STRUCTURE, PRELIMINARY DESIGN CONCEPT
SIZE L
CODE IDENT NO. 03953
DRAWING NO. 42537-131
SCALE NOTED
SHEET 1 OF 2
E-3, E-4

SECTION H-H
VIEW J-J
VIEW D-D
SECTION G-G / L-L
SECTION F-F / K-K
DETAIL E
LINEAR PLATFORM
AREA OR DEPLOYABLE PLATFORM



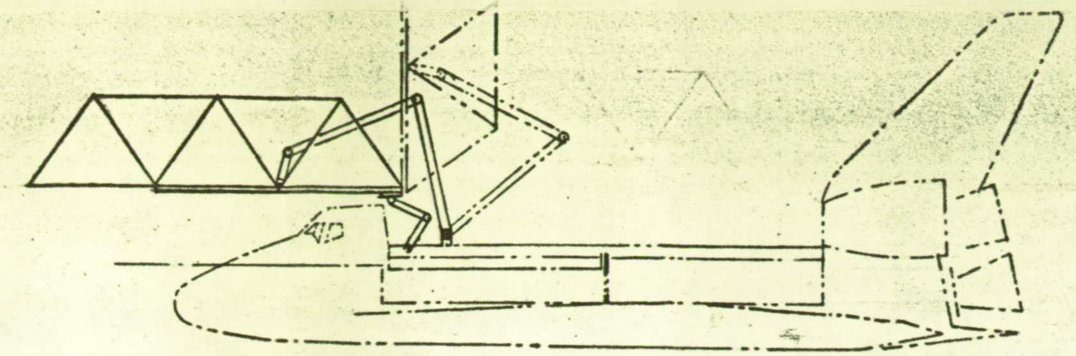
SECTION A-A

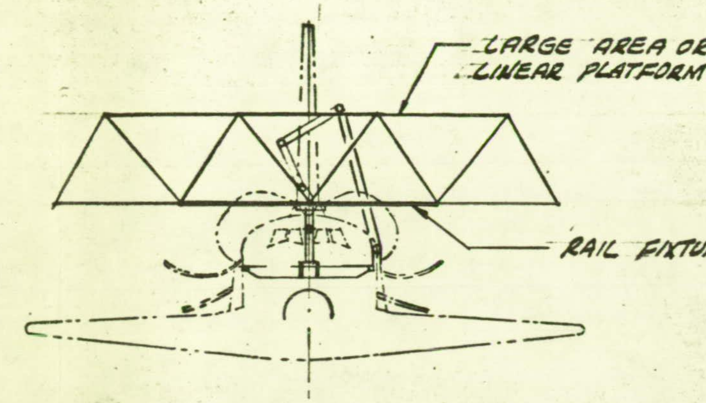


SKETCH A

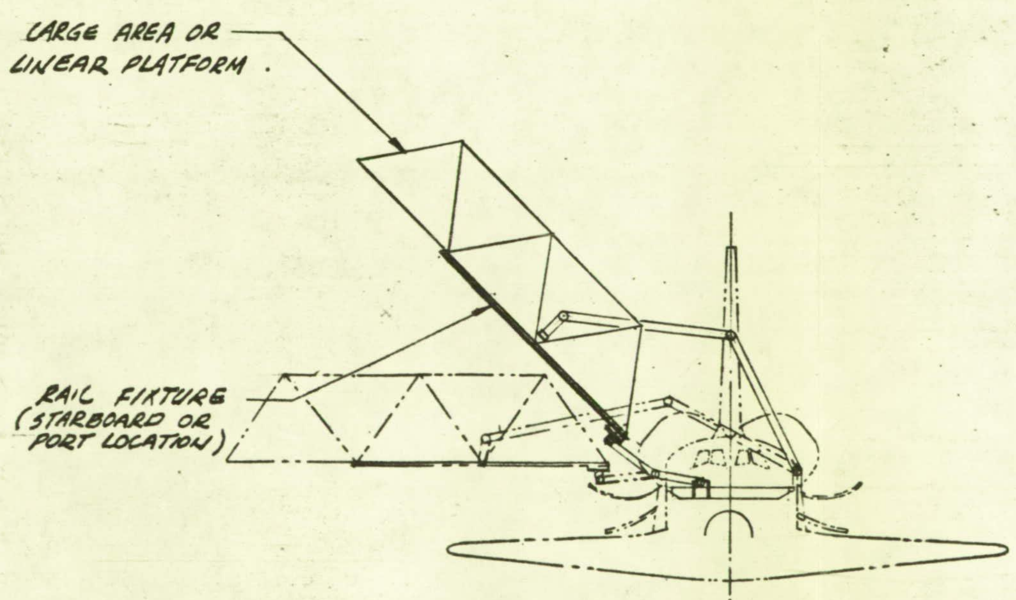
BASE FIXTURE/RAIL FIXTURE
TRANSLATION SYSTEM,
ORIENTATION STUDY

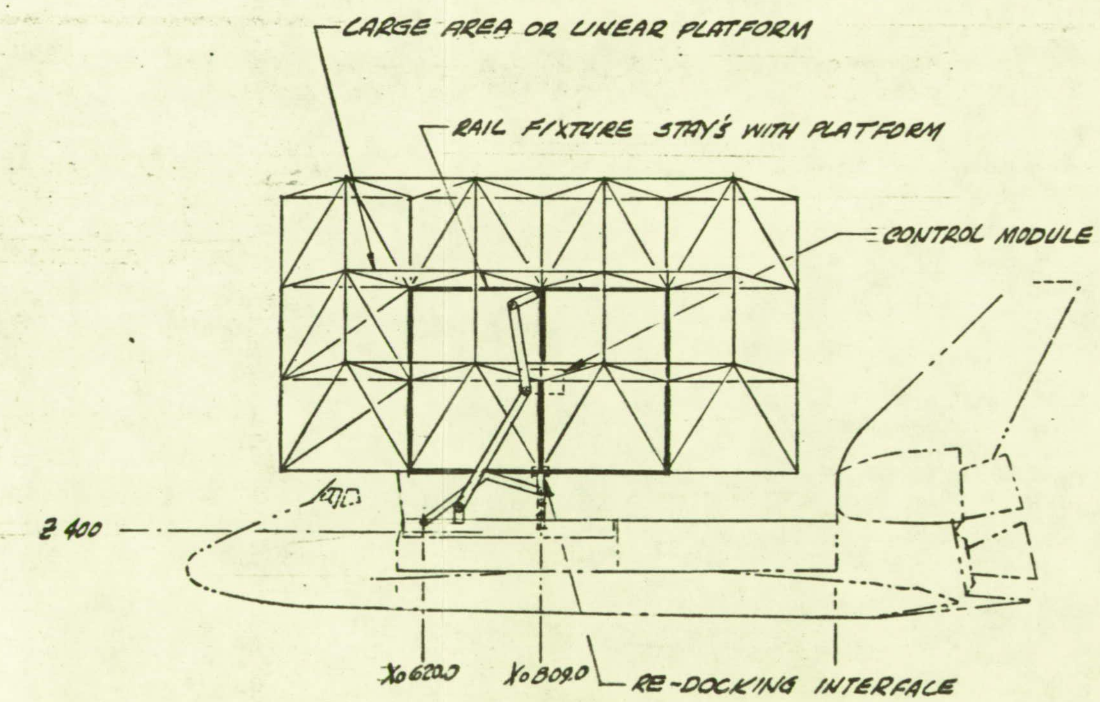
SCALE 1/150





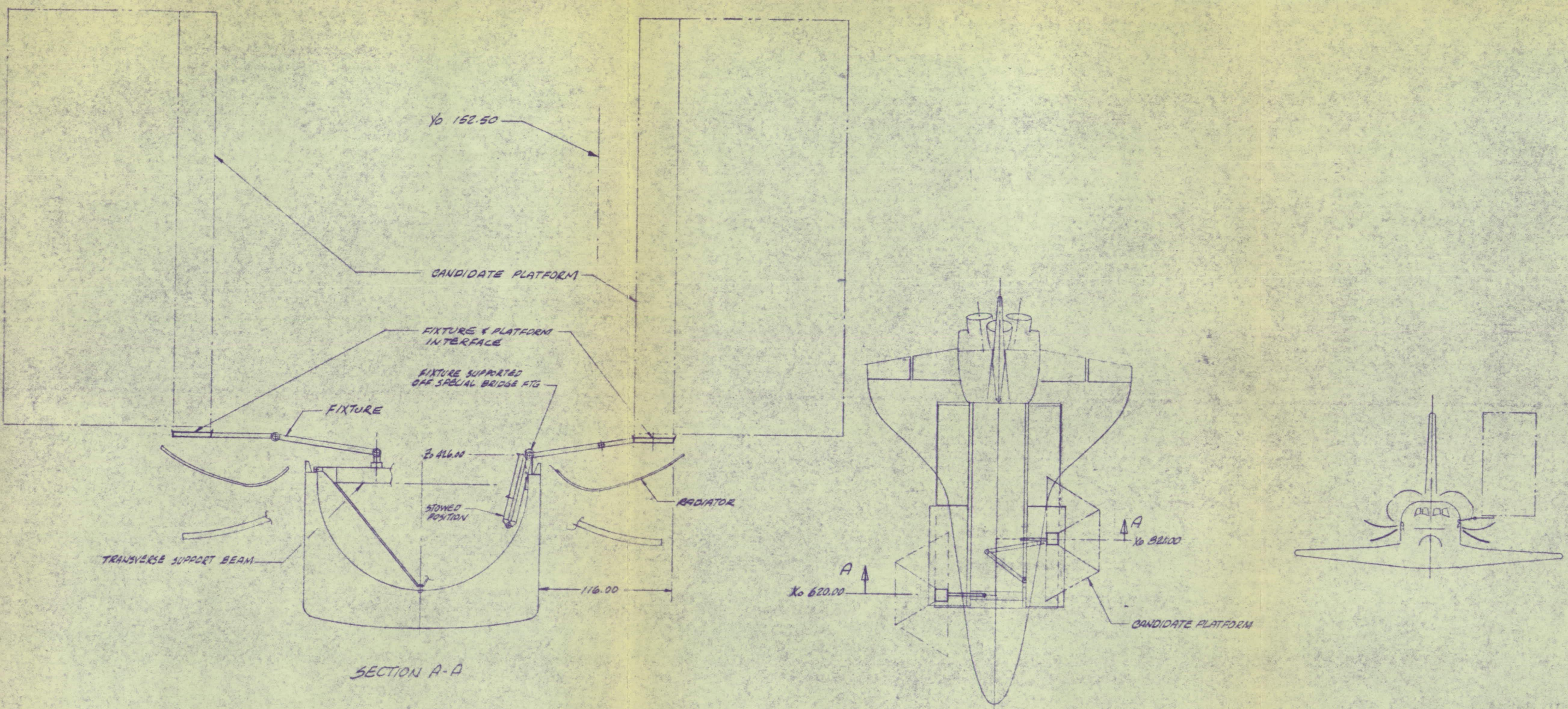
OPTIONAL CONSTRUCTION
ORIENTATION





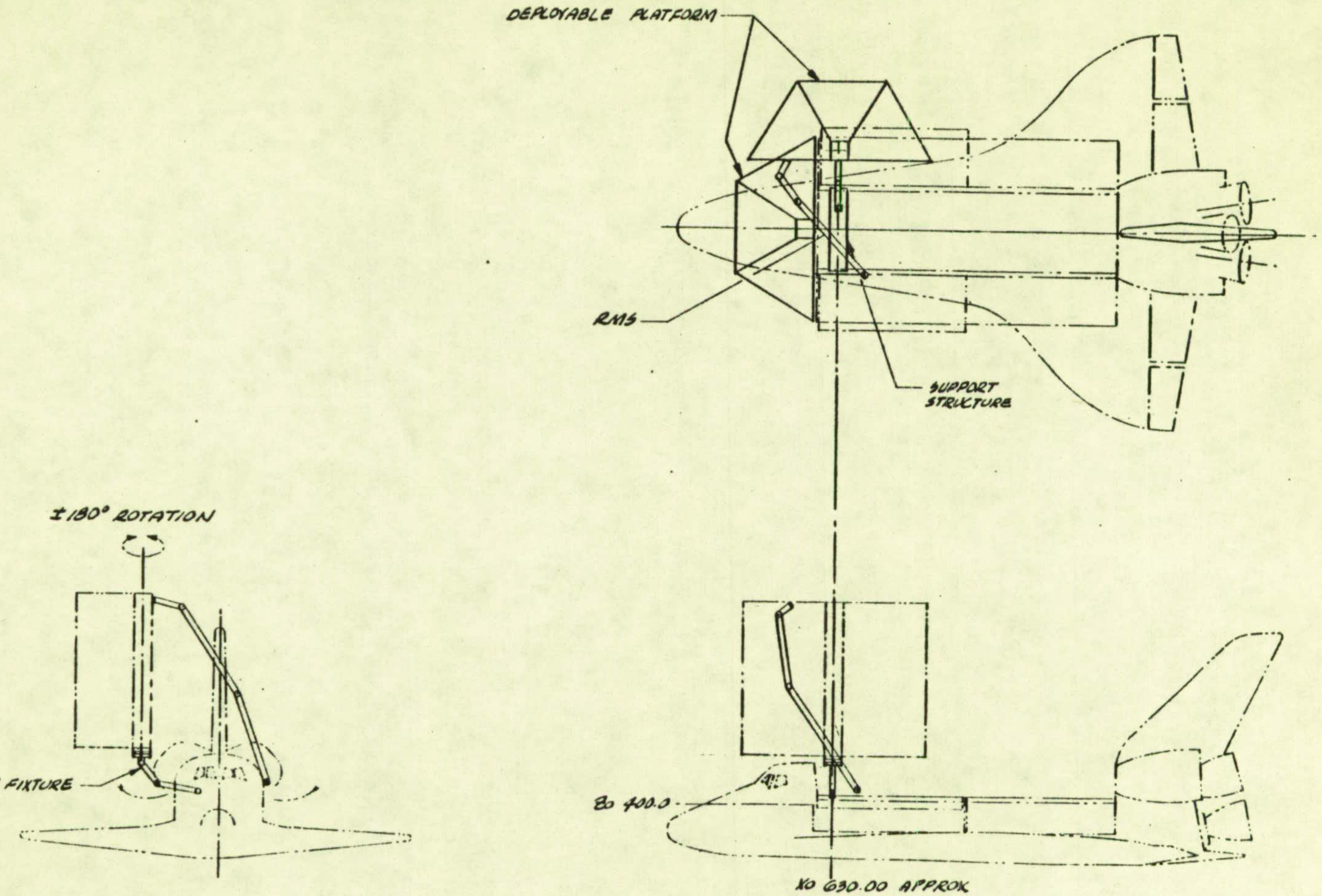
SKETCH B

ASSEMBLY FIXTURE/CANDIDATE PLATFORM
ORIENTATION STUDY
SCALE: 1/160



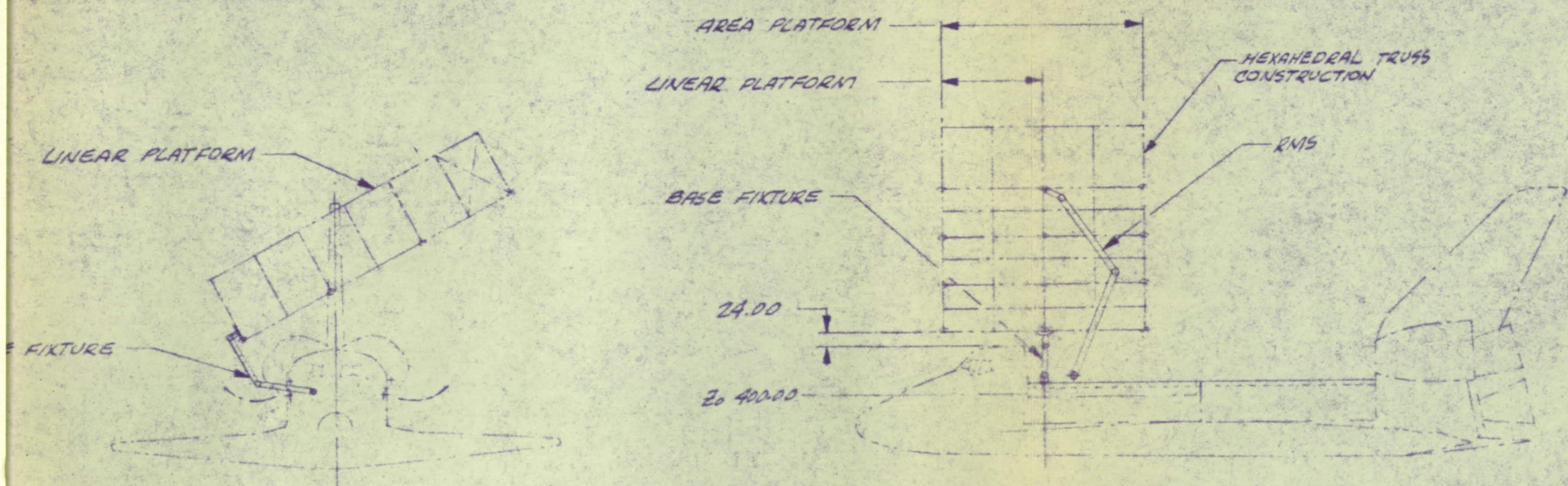
BASE FIXTURE/RAIL FIXTURE
DEPLOYABLE PLATFORM
ORIENTATION STUDY
SCALE 1/160

SKETCH C



SKETCH D

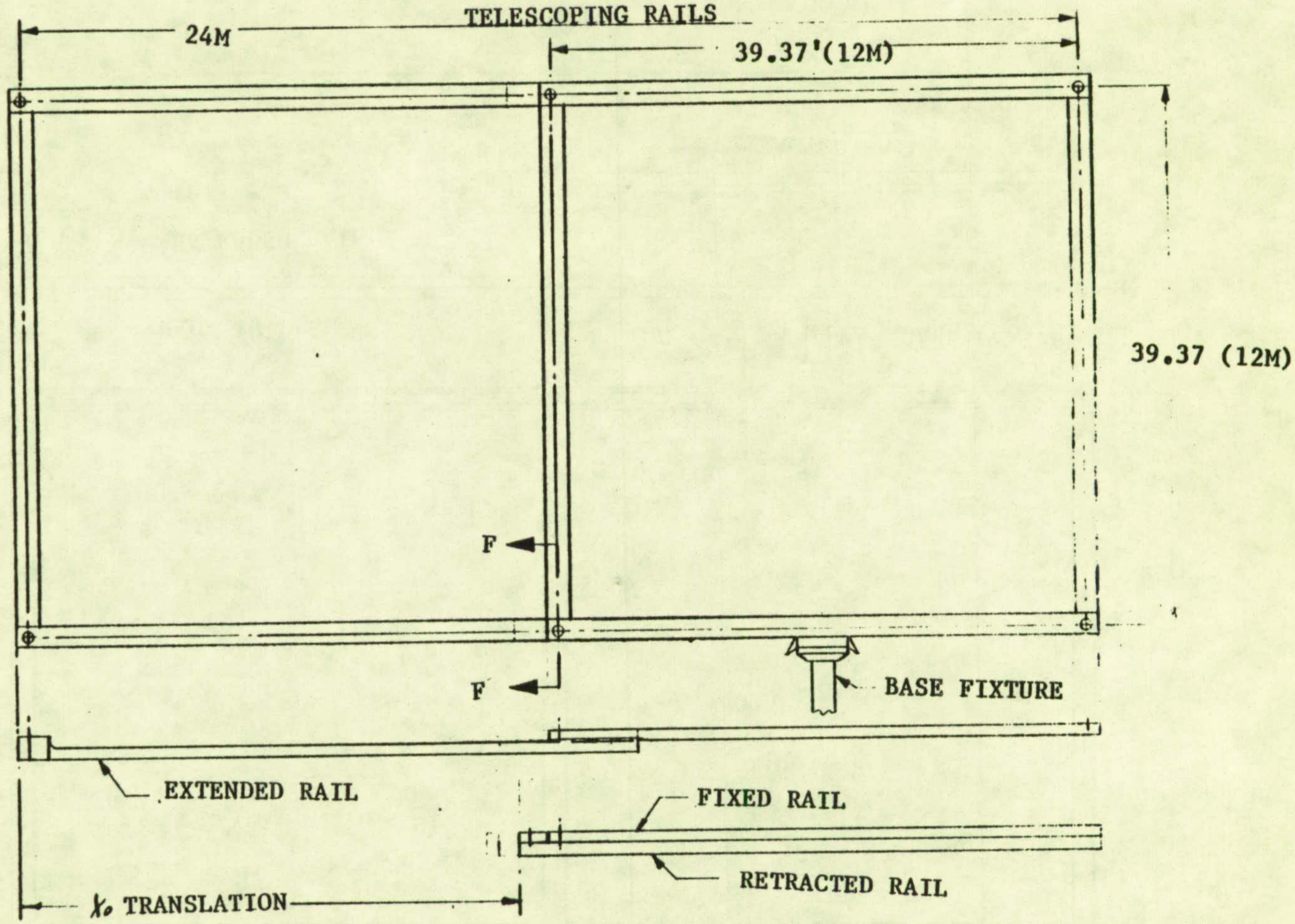
BASE FIXTURE/DEPLOYABLE PLATFORM
ORIENTATION STUDY
SCALE: 1/60



SKETCH E

BASE FIXTURE/HEXAHEDRAL
TRUSS STRUCTURE
ORIENTATION STUDY
SCALE: 1/160

ASSEMBLY FIXTURE - LINEAR PLATFORM TELESCOPING RAILS

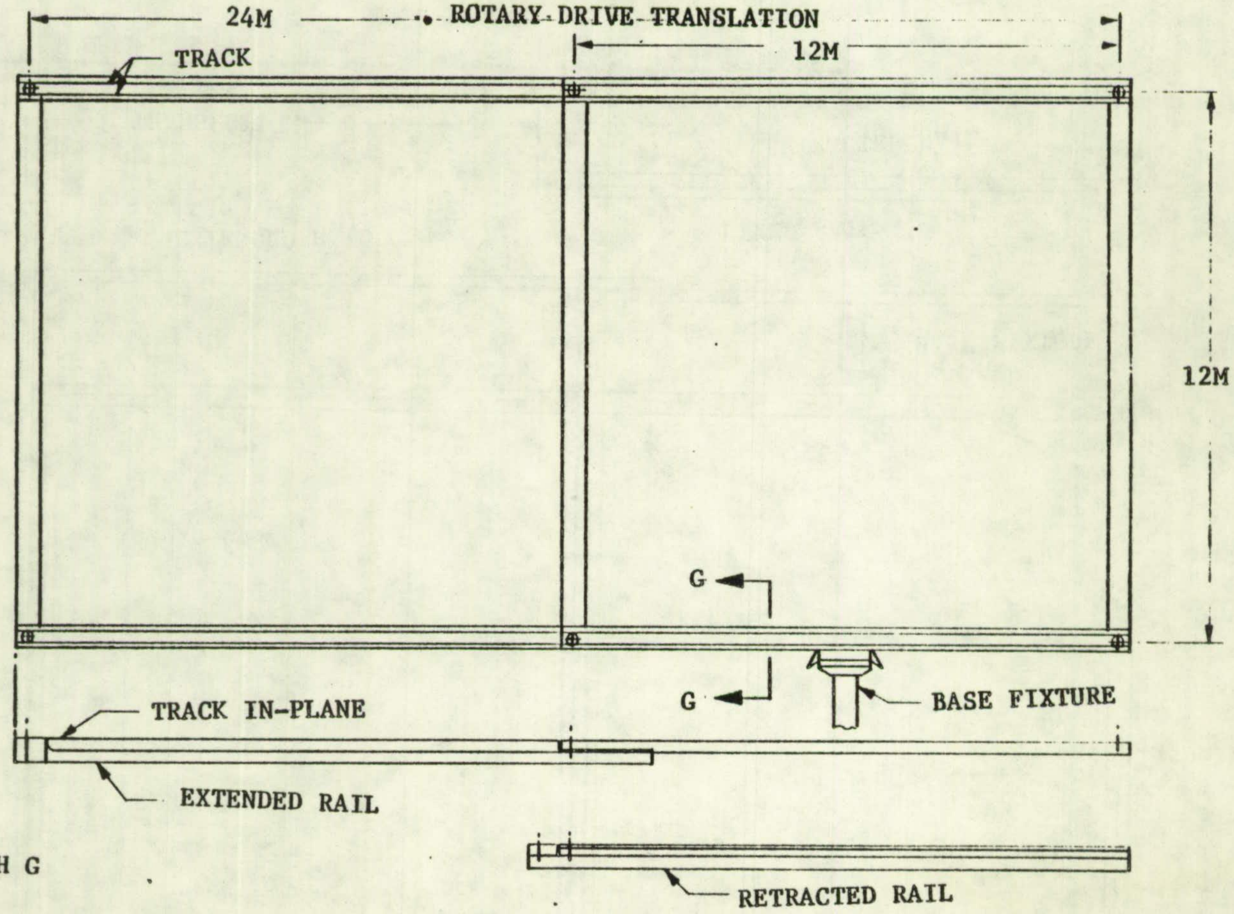


SKETCH F

ASSEMBLY FIXTURE - LINEAR PLATFORM

• DEPLOYED RAILS

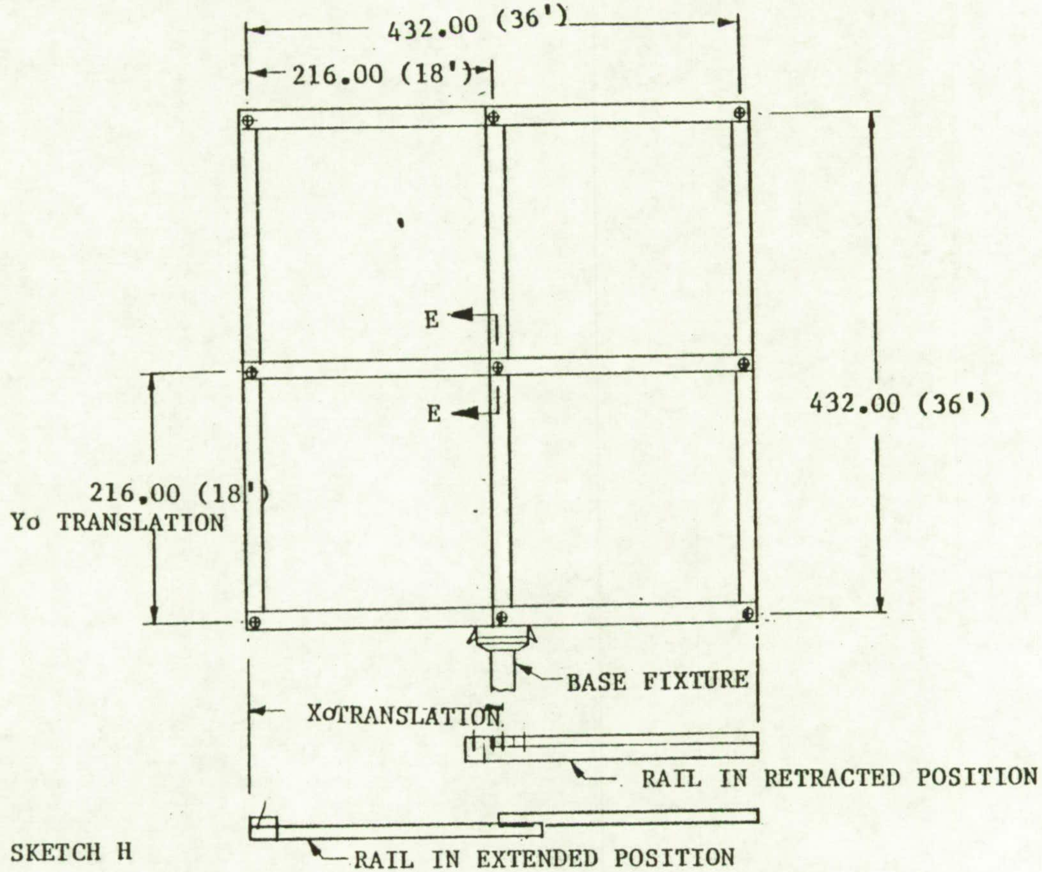
• ROTARY-DRIVE-TRANSLATION



SKETCH G

ASSEMBLY FIXTURE - AREA PLATFORM

- .TRANSLATING RAILS (Xo)
- . ROTARY DRIVE OR RMS FOR Yo TRANSLATION



SKETCH H